University of Alberta

The Coevolution of Early Hunter-Gatherer Culture and Riparian Ecosystems in the Southern Columbia River Plateau

by

Loren Gerald Davis ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the Ph.D.

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University of Alberta

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Coevolution of Early Hunter-Gatherer Culture and Riparian Ecosystems in the Southern Columbia River Plateau submitted by Loren Gerald Davis here in partial fulfillment of the requirements for the Ph.D. in Archaeology

Charles Schweger.

Charles E. Schweger

Nathaniel W. Rutter

R. LeBlanc

Raymond J. Le Blanc

Karlis Muehlenbachs

JS Nelson

Joseph Nelson

[illegible] for

Vance T. Holliday

MAY-11-2001

DEDICATION

This work is dedicated to my lovely wife, Julie. Her patience, support, and understanding through the years helped to make this a labor of love.

ABSTRACT

The Paleoarchaic-Archaic transition appears in many forms throughout the Far West, marking a prominent period of cultural change among early Holocene hunter-gatherers. In the southern Columbia River Plateau, this period of culture change is defined by the Windust-Cascade transition, which occurs between ca. 8,500 to 8,000 yr BP. Recent work in the Lower Salmon River Canyon of west-central Idaho produced a detailed archaeological and geological record spanning the late Pleistocene to early Holocene period. Changes in lithic technology, subsistence economy, and logistical organization correspond with an imbalance among ecosystemic conditions: extreme summer temperatures, heightened aridity, and marked climatic instability occur with rising mesic plant populations in riparian zones. This paradox of riparian productivity--termed the Oasis Effect--is explained by considering the fluvial geomorphology of early Holocene Plateau canyons. It will be argued that the stabilization and expansion of these productive riparian ecosystems during the early Holocene may have acted as a catalyst for the reorganization and change of cultural behaviors associated with the Windust-Cascade transition.

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CHAPTER ONE

INTRODUCTION

Introduction

At the end of the Pleistocene, reorganization of global environments followed a complex feedback system involving terrestrial and oceanic components; examples of which are seen in the suspected links between deep ocean circulation, atmospheric conditions, and the timing of continental ice melting during the decline of glacial conditions after ca. 15,000 yr BP (e.g., Ruddiman 1987; Broecker et al. 1989; Broecker and Denton 1990). Biotic responses to these global changes resulted in the expansion, movement, or extinction of many floral and faunal species within newly reorganized ecosystems (e.g., Graham and Lundelius 1984; Graham 1985, 1986, 1990; Grayson 1989; Graham and Grimm 1990; Pielou 1991). This period of massive ecological change is also associated with important events in global archaeological records, including human migration into the New World. Human settlement in most of the ice-free portions of the New World is apparently widespread by the terminal Pleistocene (ca. 11,000 yr BP). During the late Pleistocene to early Holocene (LP-EH) period, from about 11,000 to 8,000 yr BP, archaeological records throughout the New World show important new developments in hunter-gatherer culture, coinciding with the timing of rapid and often abrupt changes in environmental conditions.

One reason why the LP-EH period of transformation receives so much attention from archaeologists lies in the general belief that periods of major culture change represent laboratories for the study of the nature of culture change among hunter-gatherer societies. Studying these periods of marked change in early cultural systems may provide important clues regarding the impetus for change in hunter-gatherer culture at all times. By increasing our appreciation for how such changes occur, we can make progress towards better interpretative models of human societies in other times and places. In this study, the LP-EH prehistory the southern Columbia River Plateau region of the Pacific Northwest will be investigated in order to develop explanations for the nature of early culture change.

Post-Pleistocene Culture Change: A Topical Perspective

The importance of studying change in human culture at the LP-EH transition is reflected in a recent edited volume (Straus et al. 1996) directed at highlighting the broad appeal of this global event. Cultural transitions in the immediate post-Pleistocene period stand as a benchmark of sorts in world prehistory, representing a new chapter in the global proliferation of anatomically-modern humans. The European Paleolithic-Mesolithic transition represents one of the most intensively-studied cultural events of *Homo sapien sapien* history. Throughout continental Europe and the British Isles, the appearance of Mesolithic material culture coincides with the decline of glacial conditions, generally placed at the late Pleistocene-early Holocene boundary. The archaeological record of this transition period is marked by population growth, expansion of settlement into the evolving environmental diversity of northern Europe, new developments in lithic technology, and different patterns of resource exploitation--including an emphasis on aquatic species, small game, and wild fowl (Clark 1969). This cultural transition is also accompanied by major changes in continental ice volume, marine transgression, dispersal and extinction of vegetative and animal species, and the general reorganization of abiotic and biotic components of ecosystems under changing post-glacial climates. A common explanation for the Paleolithic-Mesolithic transition involves an adaptive response of post-Pleistocene hunter-gatherers to the demands and structure of new environmental systems, which is played out in the reorganization and manifestation of the Paleolithic lifeway into different forms, which characterize the Mesolithic culture (e.g., Childe 1925; Clark 1932; Braidwood 1963).

Binford (1968) used the topic of the Paleolithic-Mesolithic transition as a means of showing how processual concepts, with their emphasis on the functional interaction of cultural and environmental systems, could be used to address issues of culture change. Binford's (1968:324) statements emphasize the functional context of culture change: "If we hope to understand culture change in general, and the changes of the post-Pleistocene period in particular, we must seek the conditions which have brought new factors into play in the effective environments of the cultural systems at the close of the Pleistocene." Rather than invoke a symmetrical response of culture to environmental systems as an explanation, Binford suggests that different processes of population growth and settlement expansion influenced the way Mesolithic peoples interacted with their environmental contexts, setting new processes of societal organization into motion. He proposes that the manner in which resources were exploited and settlements were established during this period of transition would be predicated on the operation of different strategies for population regulation and distribution across the landscape.

The study of post-Pleistocene culture change in North America has a different history, but shares similar explanatory themes with European archaeology. The traditional view among North American archaeologists is that human settlement of the New World occurred during the close of the Pleistocene, with the spread of populations into the northern reaches continuing on into the Holocene. Throughout North America, changes in environmental systems and the material record of prehistoric societies are seen to occur differentially at scales of time, space, and character. A classic example of North American post-Pleistocene culture change comes from the Great Plains. The well-known Plano-Archaic transition marks the end of the Paleoindian era, which is partially defined by an apparent emphasis on hunting large-game--including earlier kill sites with mammoth, camel, and early forms of bison (Wormington 1957; Frison 1978). At about 8,000 yr BP, the Plains Paleoindian lifeway shifts to a more generalized Archaic foraging subsistence and settlement strategy. This transition is also accompanied by changes in lithic technology from large fluted and unfluted lanceolate projectile points to smaller, notched and otherwise diversified point styles.

The Paleoarchaic-Archaic Problem

In the Far West--considered as that portion of the North American continent that drains towards the Pacific Ocean--a cultural transition also occurs in the early Holocene, but in a different manner than seen on the Plains. The initial period of prehistory in the Far West has been characterized as a *Paleoarchaic* existence due to a lack of evidence for a subsistence system emphasizing megafauna, which is attributed to the Paleoindian lifeway (Beck and Jones 1997). Defining characteristics of the Paleoarchaic include fluted and unfluted projectile points, a generalized subsistence approach involving the exploitation of a wide variety of large and small animals, and a dispersed and mobile settlement strategy (Daugherty 1962; Bryan 1980; Ames 1988; Jennings 1989; Beck and Jones 1997). The geographic character of the Far West likely provided a level of ecological diversity not seen in the Plains. As a result, its archaeological record is more dissimilar from region to region.

A particular example of Far Western archaeological diversity at the Paleoarchaic-Archaic transition, is seen in the Columbia River Plateau (Figure 1). Leonhardy and Rice's (1970) synthesis of Lower Snake

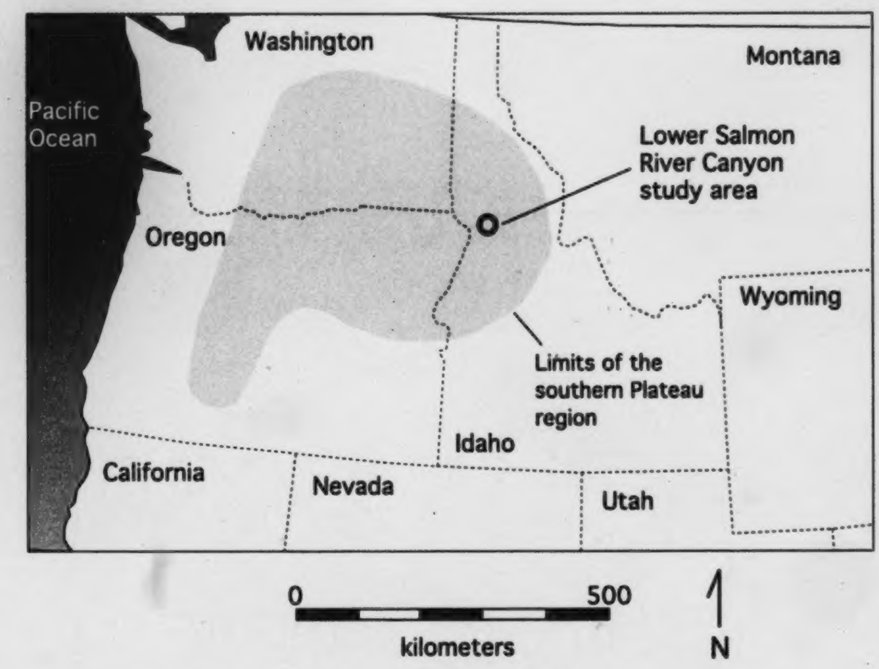
Washington
Montana
Pacific Ocean
Lower Salmon River Canyon study area
Oregon
Wyoming
Limits of the southern Plateau region
Idaho
California
Nevada
Utah
0
500
kilometers
N

Figure 1. Limits of the southern Plateau region (after Ames et al. 1998) and the location of the Lower Salmon River Canyon study area in the Pacific Northwest.

River prehistory helped to define the character and timing of the Paleoarchaic-Archaic transition in the southern Plateau region. To briefly summarize their findings: the earliest regional cultural tradition--named the Windust Phase--shows a change in lithic technology, settlement, and subsistence patterns immediately before 8,000 yr BP, after which new patterns of material culture appear, forming the basis for the definition of the Cascade Phase. The archaeological record of the Windust-Cascade transition in the Plateau forms the basis for a regional equivalent of the Paleoarchaic-Archaic cultural event. Historically, the explanations for this transition are linked to more subtle changes in the natural and social landscape of the Plateau, than caused by large-scale shifts in climate, environment, and mammalian populations--as is argued for the Plains. Perhaps as a result of the more subtle nature of both the cultural and environmental changes at the Paleoarchaic-Archaic transition in the Plateau, few specific explanations for the underlying mechanisms or factors for this cultural change are offered in the archaeological literature.

Previous Research on Early Plateau Hunter-Gatherers

Before reviewing previous explanations for the Plateau Paleoarchaic-Archaic transition, it is important that the reader is given a clear perspective on the archaeological cultures involved in this problem. Daugherty (1962) and Leonhardy and Rice (1970) provided some of the first, and most long-standing early cultural sequences for the Southern Plateau. In their models, the earliest period of human occupation--termed the Pioneer Period--is defined archaeologically by the Windust and Cascade phases, which date between 11,000 to 4,500 yr BP. Windust components are widely distributed throughout the Plateau, represented at important sites like Windust Caves (H. Rice 1965) and Marmes Rockshelter (D. Rice 1972). The lower chronometric limit for Windust components is provided by a range of radiocarbon dates that cluster between 10,600 and 10,800 yr BP (Ames 1988; Ames et al. 1981; Cole 1966; D. Rice 1972; Sheppard et al. 1987), while an upper limit is seen at ca. 8,000 yr BP. Windust phase assemblages are primarily defined by the presence of a variety of stemmed and unstemmed lanceolate projectile point forms (Leonhardy and Rice 1970; D. Rice 1972), but also include bola stones, bone tools, polyhedral cores, and various flaked lithic tools. Windust peoples exploited a range of fauna from elk (*Cervus canadensis*), deer (*Odocoileus heminonus* and *O. virginianus*), pronghorn antelope (*Antilocarpa americana*), beaver

(*Castor canadensis*), rabbits (*Lepus spp.*), to freshwater mussels (*Margaritifera falcata* and *Gonidea angulata*). Salmon remains were found in great numbers at The Dalles Roadcut site (Cressman et al. 1960), pointing to the early use of anadromous fish; however, this pattern is not widespread in Plateau sites during this period. Evidence for plant use is absent at this time, in either botanical or technological form.

Cascade phase assemblages date between about 8,000 to 4,500 yr BP, and are found to follow Windust components in the stratigraphy of several Plateau sites. The Cascade phase was divided into early (8,000 to 7,000 yr BP) and late (7,000 to 4,500 yr BP) subphases, on the basis of the later inclusion of side-notched projectile points (Leonhardy and Rice 1970). The namesake Cascade projectile point occurs in leaf-shaped lanceolate forms, with rounded or pointed bases and serrated edges also seen. Other artifacts found in Cascade assemblages include large lithic knives, steep-end unifaces (scrapers), and an increase in utilized flakes of various sizes. Cobble tools with bifacially-worked, pounded, and ground edges were employed for a wide range of activities; whereas the presence of manos are thought to reflect food grinding (perhaps seeds), the specific activity in which "edge-ground cobbles" were used is unknown.

Cascade faunal exploitation is similar to the Windust phase, with an increased use of riverine resources such as *Margaritifera falcata* and *Gonidea angulata* mussel species, and fish, including large anadromous salmonids. Sprague et al. (1968) report one of the few occurrences of bison (*Bison* sp.) with non-typological lithic tools in early Cascade subphase-age deposits. Leonhardy and Rice (1970:9) note that, "Hunting technology seems the same as in the preceding phase. Indeed, the pattern of hunting deer and elk in the canyon thickets and antelope in the upland prairies continues through to the ethnographic period."

H.S. Rice (1965) and D.G. Rice (1972:139, 215) argue that there is sufficient technological continuity between the Windust and Cascade Phases to show a evolutionary link, which also provided the basis for combining the two phases under Leonhardy and Rice's (1970) Pioneer Period. Although cultural continuity is argued for Paleoarchaic-Archaic cultures of the Southern Plateau, and is not thought to be the result of a migration of a new society into the region, the questions of how and why this transition occurred are adequately answered at this time.

Bense's (1972) study of Cascade assemblages from 13 sites in the Lower Snake River Canyon of southeastern Washington provides a view on early Holocene settlement patterns. Bense suggests a pattern of cultural continuity following the Windust Phase in which people bearing a Cascade toolkit conducted similar activities during repeated occupations of small camps along the Lower Snake River between 8,000 and 7,000 yr BP. Increased reliance on river mussels, fish, deer, and possible plant processing are said to be reflected in the faunal remains and groundstone tools found in Cascade assemblages from the Marmes Rockshelter (45FR50), Granite Point (45WT41), and Ash Cave (45WW61) sites. Bense summarizes the Cascade lifeway in the following manner:

> The settlement pattern of the Cascade phase is characterized by non-nucleated settlements dispersed throughout the river canyon. Each settlement is relatively small (less than 50 meters in diameter) and most likely supported no more than 20 to 30 persons. At each location a variety of activities were performed: butchering, cooking, fishing, food and hide processing, tool manufacture, and general residence. At each site consistency through time of these activities is indicated by thick uniform cultural deposits and large numbers of similar artifact types. The people regularly reoccupied the settlements for similar purposes. (Bense 1972:105)

Interpretative Models of Early Hunter-Gatherer Organization

Although the problem of the Paleoarchaic-Archaic transition in the Southern Plateau was identified over thirty years ago, few archaeological studies attempted to establish the conditions and mechanisms associated with this period of early culture change. Instead, only a handful of explanations are available, typically found in the closing statements of larger archaeological reports. These explanations for the Plateau Paleoarchaic-Archaic transition can be grouped into two major themes.

Explanations that fall under the heading of the first theme take various forms, but basically state that culture change occurs as a result of an unspecified process of "adapting" to the overwhelming influence of post-glacial environmental warming and drying, which hypothetically caused ecological degradation in the Plateau. These explanations typically appear as statements in which environmental and cultural changes are assumed to share a causal relationship, with the former responsible for the manifestation of the latter (e.g., Frison and Bonnichsen (1996:304) for an extra-regional example). This perspective can be seen in the development of interpretative models of Plateau prehistory during the 1950s to 1970s, which parallel the paleoenvironmental research of Hansen (1942, 1947) and Antevs (1948, 1955) in western North America. An example of this influence can be seen in Daugherty's (1962:144-147) Intermontaine Western cultural chronology, in which the manifestation of Plateau hunter-gatherer culture is broken down into periods that correlate to Antevs' (1948, 1955) proposed Neothermal climatic model (Wildesen 1982:82). Wildesen's (1982:82) summary of late Pleistocene to middle Holocene hunter-gatherer logistical organization draws from this causal perspective as well, as she states, "In general, peoples throughout the Plateau seem to have shifted from a generalized way of life to one that was more specialized about the time of the climatic change represented by the Altithermal, although the specific nature and timing of this shift varies from place to place..."

While some degree of influence is expected to be derived from the natural ecological context of prehistoric hunter-gatherers, it is difficult to adopt generalized causal associations between the timing of environmental and cultural change as an effective explanatory device. Admittedly, identifying the co-occurrence of cultural changes in archaeological assemblages with components of their associated environmental context is an important first step in the evaluation of potential explanations of culture change; however, failing to develop and expand upon the observation of these correlations produces a non-explanation, at best. This explanatory theme is commonly seen in the archaeological literature of the Plateau that deals with early culture change. These explanations are little more than the starting points of potential arguments, lacking the level of detailed study that is required to show the manner in which human cultural and environmental contexts are linked, if at all.

A second form of explanation moves away from the direct correlation of environment and culture, but also tends to provide few insights on the process of culture change. This usually takes the form of statements to the effect that: following an initial period of pioneering and settlement, a lengthy "settling in" process (e.g., Reid and Gallison 1996:40) occurs, which causes hunter-gatherer groups to follow a path toward decreased mobility and increased population density. The effects of these logistical and demographic changes are argued to be reflected in the material culture of Archaic peoples, representing a visible transition in the archaeological record.

These explanations are typically accompanied by more thoughtful consideration of the archaeological data, and show an interest in breaking away from mechanistic explanations based on environmental determinism. As with the first theme, however, explanations of the second type often suffer from the presentation of vague statements or take the form of basic descriptions that offer little or no basis for interpreting the origins of the observed archaeological patterns, and provide few detailed insights as to why certain changes appear over others. Schalk (1980; see also Schalk and Cleveland 1983) describes late Pleistocene to early Holocene hunter-gatherers mobility and logistical organization as having operated under a broad spectrum foraging strategy for the period between 11,500 to 4,200 yr BP. During this time, hunter-gatherers acted as foragers (*sensu* Binford 1980), employing generalized toolkits and frequent movement across the landscape to take advantage of a wide range of plant and animal resources. Schalk and Cleveland (1983) admit that the model may not account for all variabilty seen in Plateau sites through time, but is intended as a general framework to explain common trends seen in regional prehistory.

A broad spectrum foraging model was employed by Meatte (1990) to explain the early prehistory of southern Idaho's western Snake River Basin and adjacent areas of Oregon and Nevada. Meatte recognized several subsistence and technological changes at 8,000 yr BP in the western Snake River Basin, including the exploitation of a greater range of foods, the introduction of new, specialized tool types, and an increased diversity in point styles; however, as seen in Schalk (1980), explanations why these changes in culture came about are not provided. In both examples, Schalk's broad spectrum foraging model is more valuable as a classificatory than an explanatory device. Why early hunter-gatherers maintained the same foraging strategy throughout the Plateau's LP-EH environmental evolution is but one question that is left unanswered here.

In his synthesis of Far Western prehistory, Carlson (1983) argues that the interactions between four distinct basal cultures acted as a catalyst for early Holocene culture change. These four basal cultures are seen between 13,000 and 10,000 yr BP, and include: a Stemmed Point tradition; a Fluted Point tradition; a Cobble Tool tradition; and a Microblade tradition. Each tradition is viewed as filling a certain ecological niche in the LP-EH Far West. Peoples of the Stemmed Point tradition, for example, "occupied a niche as hunters and forageres around the pluvial lakes, which then stretched from interior Oregon to southern California" (Carlson 1983:93). Fluted Point-bearing peoples likely split from the Stemmed Point tradition, "in pursuit of both mammoth meat and machismo, and in the course of hunting mammoth expanded geographically across the continent to the east and north" (Carlson 1983:93). Foragers bearing the Pebble Tool tradition show an emphasis on coastal and riverine resources, while those with a Microblade tradition apparently emphasized the subsistence resources of coastal and northern interior areas.

Under Carlson's (1983) model, culture change occurred through the effects of diffusion, following intergroup contact, and/or as a result of an undefined process of adapting to new and changing environmental contexts. An example of this diffusion process seen in the interaction between peoples of the Stemmed Point tradition and the Cobble Tool tradition:

> By 10,000 yr B.P., the stemmed point hunters had expanded eastward across the Rockies and northward into the drainages of the Columbia and Snake Rivers. They came into contact with another culture, one that used pebbles tools and leaf-shaped points, relied on coastal and river resources, and was spreading up the rivers following the salmon runs.

This contact possibly produced the Cascade Phase (Leonhardy and Rice 1970), which Carlson (1983:90) considers to represent a likely "interface" between the Stemmed Point and Cobble Tool tradition. Carlson's second process of culture change is reminiscent of other deterministic environmental forcing models used in the Plateau, and is described in the following manner:

> In the upriver areas of the Columbia and Snake, and possibly the Fraser, cultures belonging to the Stemmed Point tradition persisted until changed into cultures relying as much or more on the salmonids

> as on mammalian fauna. In the Great Basin, this tradition was associated with the pluvial lakes and disappeared with the demise of that environmental system. (Carlson 1983:83)

Since the original cultures were closely tied to a specific ecological niche of the Far West, Carlson argues that post-Pleistocene environmental change had different effects on the groups. The disappearance of the Fluted Point tradition is linked to the demise of Pleistocene megafauna, while the decline of the Stemmed Point tradition, as shown above, is related to the onset of xeric conditions during the Holocene.

This model suffers from a number of shortcomings, which make its use difficult. Most notably, the concept that point traditions are inseparable from distinct societies--i.e., the presence of stemmed points means that people of the Stemmed Point tradition were present as well--is cumbersome, and calls into question the reality of point styles as markers of distinct cultural groups. Projectile points, like other aspects of material culture, represent ideas--ideas that can be transmitted between groups bearing different technological traditions without the requirement of genetic exchange. Thus, it is questionable whether we need to invoke the actual migration of a people along with their ideas. As well, Carlson fails to clarify the process through which one culture is "changed into" another, placing further limitations on the applicability of his model as an explanatory device.

Ames (1988) presents a model of early forager mobility strategies for Southern Columbia Plateau hunter-gatherers on the basis of 13 assemblages from early to middle Holocene-age archaeological components in eastern Washington, north-central Idaho, and northeastern Oregon. Ames states that early Southern Plateau hunter-gatherers show a shift in logistical organization from collectors to foragers across the Paleoarchaic-Archaic transition period. Briefly stated explanations for the reasons behind this early culture change touch on issues of reproductive success and post-glacial environmental productivity (Ames 1988:335-336):

> At some point in the annual cycle, large temporary aggregations might form at very productive places--such as the major fisheries at the Dalles

> on the Columbia and the canyon of the Fraser River. The aggregations would be crucial to the reproductive success of a thinly dispersed population since they would allow individuals to find mates.

Under this adaptive strategy, Ames feels that the Cascade peoples employed a high degree of residential mobility, using a wide range of resources as they moved through large territories, with no significant reliance on riverine resources apart from those "very productive areas" where fishing was highly rewarding.

Towards an Ecological Study of Early Plateau Culture Change

Simply pointing out how apparent increases in annual temperature during Antevs' Altithermal (Antevs 1955) correspond with the appearance of the Cascade Phase does little to explain *why* this happened, or *how* such changes in culture possibly occurred. These kinds of explanations nearly always rely on the acceptance of a causal environmental-cultural relationship. Because of this, a clear perspective of the applicable environmental context and how it created opportunties and/or constraints for the operation of hunter-gatherer adaptive strategies is also nearly always missing in this line of reasoning. Although we might argue that increasing aridity during the early and middle Holocene likely produced tangible ecological effects, perhaps seen as a reorganization of nearly all biotic and abiotic parameters of Plateau ecosystems, we currently lack a sufficiently representative database to support or refute this assertion. Because our knowledge of LP-EH Plateau paleoecology is incomplete, it is difficult to evaluate how ecological change affected early hunter-gatherers, if at all.

Claiming that the current state of Plateau paleoenvironmental knowledge is not suited to clearly perceive the prehistoric context of LP-EH hunter-gatherer lifeways must be qualified, given the long and productive history of earth science study in the Pacific Northwest. Qualification for this claim is based on two aspects: (1) river canyons provided a critical ecological niche for Plateau hunter-gatherers throughout prehistory; and (2) within the Plateau, our knowledge of how LP-EH paleoenvironmental conditions and change influenced the specific ecological conditions of river canyons is largely incomplete.

When hunter-gatherers first ventured onto the Columbia River Plateau, they undoubtedly recognized the contrasts present between the dry upland prairies and forests, and the more mesic areas along rivers and streams. Rivers and the microenvironments that surround them are typically marked by a high density and diversity of animal and plant life. This zone of biotic richness is characteristic of riparian ecosystems (Malanson 1993). The microclimatic effects of river valleys, coulees, and canyons can give refuge to plants, animals, and people in the midst of more rigorous environmental surroundings, such as that found in the semi-arid Southern Plateau. Riparian ecosystems commonly provide reliable sources of subsistence for hunter-gatherers as well: anadromous fish runs, waterfowl migrations, and mammal overwintering can produce high spatial densities of food sources at certain times of the year. In addition to seasonal resources, resident shellfish, fish, mammal, and bird populations can also be found along the river, providing a more modest but reliable year-round subsistence base (Brown 1997).

The basic attractiveness of riparian ecosystems to Plateau hunter-gatherer societies is supported by the prehistoric record, as the regional archaeological database is largely recovered from sites in riverine settings. Admittedly, some of this is due to historical events, which served to emphasize the investigation of riverine sites. Beginning in the 1950s, Pacific Northwest archaeological excavations were conducted the concert with state highway projects and construction of several hydroelectric dams by the Army Corps of Engineers on many of the Plateau's major rivers. Archaeological salvage projects incorporated into these construction projects led to the recovery of great amounts of information, which provided graduate theses and dissertations for a generation of archaeologists (Lohse and Sprague 1998), and data for syntheses of regional prehistory (Cressman et al. 1960; Daugherty 1962; Browman and Munsell 1969, 1972; Nelson 1969, 1973; Leonhardy and Rice 1970). Despite this imbalance in investigative energy, upland sites typically fail to produce the diversity and richness of lowland canyon and coulee sites. This is partially due to differences between the structural nature of upland and lowland ecosystems, which leads us to another reason for the apparent attractiveness of Plateau riparian ecosystems.

Plateau river canyons and coulees retain high spatial densities of biotic resources, while upland prairies and forests are typically marked by more dispersed animal and plant populations. Thus, we should expect that sites along rivers should reflect the periodic reuse of spatially stable (relatively speaking) riparian resources, which can be seen as a stratified record of human occupation. The dispersed nature of upland resources should be seen in the spatial distribution of upland sites and their lower yield of archaeological data, as compared to lowland sites.

Support for the second aspect--that our knowledge of Plateau riparian ecosystems is incomplete--is found in the fact that most information on regional LP-EH environmental conditions comes from studies largely conducted in upland settings or adapted from neighboring regions. Pollen records (e.g., Hansen 1942, 1947; Mehringer et al. 1977; Mack et al. 1978; Barnosky 1985; Mehringer 1985; Sea and Whitlock 1995), glacial chronologies (e.g., Davis 1988), faunal records (e.g., Gustafson 1972; Grayson 1976, 1977, 1989, 1998; Lyman 1992), and synthetic paleoenvironmental histories (Antevs 1948, 1955) provide the majority of information on this account. Of the studies conducted on Plateau rivers, the stratigraphic and geomorphic nature of fluvial systems is emphasized (e.g., Daugherty et al. 1967; Hammatt 1976; Mierendorf 1984; Chatters and Hoover 1986, 1992; Welford 1988; Gough 1995), with limited discussion on riparian paleoecology provided in only a few cases (e.g., Hammatt 1976). Because of this, our knowledge of Plateau river canyon ecology lags behind our appreciation of upland paleoecology.

Just as we can appreciate the marked difference between upland and canyon ecosystems in the Plateau, and the relative importance of riverine contexts to early hunter-gatherers, we should ask the question of whether upland proxy records provide an adequate means of evaluating the entire paleoenvironmental context of early prehistoric peoples. Based on the above discussion, my answer would be a negative one. Therefore, a productive starting point for investigating the Plateau Paleoarchaic-Archaic transition should include a reductionist standpoint, involving an investigation of the interrelationship between early hunter-gatherer adaptive strategies and the changing nature of riparian paleoecology. To remedy this, we must develop models that clarify the opportunities and constraints that were potentially imposed by changes in specific environmental systems during the late Pleistocene to early Holocene. Only then, we might be able to make informed evaluations about the role changing Plateau ecology possibly played in hunter-gatherer cultural change.

Statement of Research Problem

Archaeological studies of the Paleoarchaic-Archaic transition in the Plateau traditionally fail to provide empirical perspectives on the evolution of late Pleistocene to early Holocene riparian ecosystems, and how ecosystemic change affected the patterning and distribution of resources used by early hunter-gatherers. As a result, we are unable to adequately evaluate the manner in which the dynamism of riparian ecosystems influenced the choices hunter-gatherers made in organizing economic, technological, and logistical aspects of their cultural systems. Using both archaeological and geoarchaeological approaches, I will study the interaction of late Pleistocene to early Holocene hunter-gatherers with a changing riparian ecosystem in a portion of the Lower Salmon River Canyon of west-central Idaho (Figure 1). The basis for this human-environmental interaction will be inferred from records of settlement, technological, and subsistence organization in several achaeological assemblages spanning the Paleoarchaic-Archaic transition. Explanations for observed changes in these archaeological assemblages will be developed from a consideration of the selective pressures that potentially were operating in early Plateau riparian ecosystems, and the possible adaptive benefits and unintended consequences they held for early Plateau hunter-gatherers.

Organization of Study

This dissertation was written in a manner that combines the style of traditional manuscript and paper format approaches. As a result, some sections are prepared as papers for publication and others are presented simply as unpublished chapters, in the traditional dissertation format. Those papers prepared for publication include mention of the journal that the paper was submitted to or accepted by. Because of the interdisciplinary nature of the research problem, the reader is presented with a large amount of background information in the initial chapters, with efforts to synthesize and interpret the large database provided in the final chapters. Many chapters provide paleoecological and archaeological information that extends beyond the temporal context of the Paleoarchaic-Archaic transition. The inclusion of this additional information is important, as it satifies requirements of the challenge cost share agreement between the University of Alberta and the Bureau of Land Management that largely funded the field work and laboratory analyses. To maintain a suitable focus, however, extended discussion on the implications of the information beyond the immediate research problem will be kept at a minimum.

The remainder of the dissertation is organized in the following manner: Chapter Two outlines the theoretical and methodological framework that will guide the collection, treatment, and interpretation of necessary data. This chapter sets the tone for the topics of Chapters Three through Six, which present information on the geology, paleoclimatic, and paleoecological context of riparian environments in the study area. Chapters Seven, Eight, and Nine outline the early archaeology and geoarchaeology of sites excavated in the study area. Analysis and interpretation of the relationship between the early riparian paleoecology and archaeological records of the Lower Salmon River Canyon are presented in Chapter Ten, along with discussion concerning new explanations for the Paleoarchaic-Archaic transition in the Plateau.

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CHAPTER TWO

A THEORETICAL AND METHODOLOGICAL FRAMEWORK FOR STUDYING EARLY HUNTER-GATHERER USE OF RIPARIAN ECOSYSTEMS

Introduction

This chapter will present a methodological framework that will be used to collect, interpret, and integrate archaeological and geologic information into a model of hunter-gatherer use of riparian ecosystems. While specifically designed for the river canyons of the Columbia River Plateau, the approach presented here can be easily adopted and modified for use in other regions with different ecological factors to consider.

Interpreting Culture Change

In order to effectively address the problem of the Paleoarchaic-Archaic transition, the collection and organization of required information must be orchestrated along suitable theoretical guidelines. In keeping with earlier discussion, we must use theory that can evaluate the potential selective pressures that were present in LP-EH Plateau environments, and how the cultural behaviors of early hunter-gatherers were affected by these pressures. Recent application of Darwinian evolutionary concepts offer fertile grounds for investigating a problem such as the Paleoarchaic-Archaic transition. This use of evolutionary concepts, often referred to as Darwinian or Selectivist theory in their archaeological applications, show greater potential for developing explanations of archaeological phenomena than other theoretical perspectives. This is due to its concern with environmental contexts as a source of selective pressure, human decisions within those contexts, and the consequences that those decisions might have on the way certain cultural patterns are replicated through time.

As might be expected, different schools of thought exist among the practioners of Darwinian archaeology. At one end of the spectrum, more conservative views rooted in sociobiology treats cultural behavior merely as an extension of the human genome, with behavioral patterns dictated by one's genes. At the other end, a relativistic view of evolutionary theory exists, with human intentionality and altruism dictating the form and replication of cultural behaviors and natural selection playing only the smallest part in explaining culture change. Most examples of Darwinian archaeology, including that which is advocated in this study, fall in between these two extremes.

A crucial distinction is drawn between evolutionary ecology and neo-Darwinian theory, primarily on the basis of the latter's inclusion of a separate mechanism for the transmission of cultural behaviors (Bettinger 1991). Cultural transmission models used within a Darwinian evolutionary framework maintain that the transfer of cultural behaviors must be treated differently than its genetic counterpart. The transfer of genetic and cultural information is therefore considered to occur in asymmetric patterns. This can be seen in the fact that genetic information is passed along from only two persons at a time--one's biological mother and father; while cultural information may be transmitted to an individual from his family, social group, or society. From this standpoint, a neo-Darwinian approach with an inclusive model of cultural transmission assumes, "...that culture is an extrasomatic means of transmitting programs of behavior and that because it is extrasomatic may not lead to behaviors that conform to the expectations arising from models in which reproduction is genetic" (Bettinger 1991:223). It is this concern with making the distinction that cultural behavior is not somatically-based (i.e., that an individual's behavior is provided, and literally determined, by his or her genes) that allows for the treatment of cultural behavior in a more productive arena.

Definitions

Terms originally associated with Darwin's theory of evolution are commonplace in the archaeological literature. In order to avoid confusion as to the meaning of specific terms related to Darwinian evolution, as they are applied to human culture, some definitions should be provided. Darwinian evolution, as considered in both biological and selectionist terms, is defined as, "a particular framework for explaining change as differential persistence of variability" (Dunnell 1980:38). Evolutionary archaeology emphasizes the measurement and interpretation of change as a way to account for variability, which is the target of selective pressures: "Variability is the potential for variation to be produced. Selection operates upon actual *variants* that are produced" (O'Brien and Holland 1995:183). The production of variability, through the evolutionary process of natural selection, is undirected. This is in contrast with processual applications of evolution, which emphasized adaptation in terms of progressive development (e.g., White 1943, 1947, 1959). A correct Darwinian perspective would not expect, indeed cannot predict, the outcome of the selective process. The outcome of selection, or simply that which "evolves" follows,

"...a replacement-based process that produces new kinds; it does not gradually transform one thing into another" (O'Brien and Holland 1995:186; Dunnell 1980). Adaptation, then, is considered the, "morphological, physiological, and behavioral equipment of a species or a member of a species that permits it to compete successfully with other members of its own species of with individuals of other species and that permits it to tolerate the extant physical environment" (Mayr 1988:135). Mithen (1989:488) provides an expanded definition of adaptation that conforms to a Darwinian perspective:

> Adaptation is about staying alive and reproducing in competition with other individuals. It is not about achieving some optimal state of behavior. Individuals should be seen as attempting to improve their current performance in relation to others, not seeking the very best (Dawkins 1982:46). They may be attempting to improve their foraging efficiency, access to mates, degree of stylistic conformity in pot decoration, or any other means by which they engage in the process of adaptation to their social and physical environment.

It is perhaps easier to talk about studying adaptations than it is to produce data that address adaptive behavior among prehistoric peoples. On this account, O'Brien and Holland (1995:192) stress the importance of being concerned with the problems and not the solutions in evolutionary research, warning that, "...it must be kept squarely in mind that the link between determining certain features to be adaptations and deciding what the features are adaptations *for* rests on inference" (emphasis in original). Clovis points and shell-tempered ceramics are examples of solutions to specific problems in the past, say the authors. By focusing on what the problems were that could be solved by the adoption of a different strategy, say, the invention of a tool, or by establishing trading alliances, archaeologists are better positioned to address past behaviors from an evolutionary perspective. Another example might be that while the adoption of blade technology at the expense of biface production can be explained as a need for the increase in cutting edge per unit of lithic material, it fails to identify why the need for more cutting edge existed in the first place--that is, what problem was being solved by the switch to blades over bifaces?

How then can we address the problem of the Paleoarchaic-Archaic transition in the LSRC in evolutionary terms? First, it is necessary to establish the data in a framework that is consistent with Darwinian evolution; namely, the nature of the variability in question must be empirically defined in a temporal format. This task will be accomplished by quantifying the diachronic dataset of site assemblage and subsistence data from the LSRC. Next, we must ask how the, "differential representation of transmitted variability in subsequent states" (Dunnell 1980:37) is reflected in our archaeological dataset. The statistical treatment of assemblage data may provide an answer here, in terms of its relationship to patterns of foraging behaviors during the late Pleistocene to early Holocene period. Finally, we must explain the observed variation in terms of its evolutionary fitness (O'Brien and Holland 1995). On this last point, Bettinger (1991:219) reminds us that, "Because in Darwinian theory evolutionary outcomes (consequences) are purely opportunistic, ungoverned by any grand design, the locus and action of reproduction and selection must be specified exactly to produce any expectation about consequence at all." Selection does not occur in a time or place removed from any contextual basis. Indeed, selective forces are derived from the natural or social environment. Selective pressures operate against individuals bearing these behaviors, "*at a particular time and in a particular place*" (O'Brien and Holland 1995:181, emphasis in original). Because human behaviors are selected against, rather than selected for, we are able to view the archaeological record as a history of behavioral successes outcompeting less suitable strategies for survival.

Cultural Transmission

Dunnell (1980) acknowledges that, while the fact that cultural behaviors should be transmitable, just as genetic information is transmitable, the mode in which this transmission occurs is unclear, and represents a serious obstacle to the operationalization of evolutionary theory in archaeology. Boyd and Richerson (1985) suggest several mechanisms through which cultural behaviors may be transmitted that provide an alternative to adopting a genetic analogy of transmission. These methods of transmission include *guided variation*, *frequency-dependent adoption*, and *indirect bias*. Guided variation (Boyd and

Richerson 1985:95) occurs when an individual considers a range of possible examples of a particular behavior (e.g., making and employing a style of projectile point), chooses to imitate the mean of the possibilities, and fine-tunes the behavior through trial and error. Frequency-dependent adoption (Boyd and Richerson 1985:208-209) involves a process in which an individual adopts those cultural behaviors that are most commonly observed. In the operation of indirect bias, individuals choose among a ranked set of behavioral aspects, as ordered by social determination. Because the set includes other behavioral aspects that are grouped along with the desired or imitated behavior, the individual ends up adopting other cultural behaviors included in the set (e.g., semi-subterreanean pit house structure style is adopted as part of the set of behaviors associated with intensive salmon harvesting and storage). These last two culture transmission models are driven by social factors and are jointly referred to as "social transmission."

Concern For the Ecological Context

If much of the selective pressures that operate on human behavior are derived from their ecological context, then we must integrate suitable methods and concepts to account for the character and change of environmental parameters that operated during the Paleoarchaic-Archaic transition. Butzer's (1982) approach to the study of human-environmental interaction advocates the use of multidisciplinary approaches to model aspects of past ecological contexts. Butzer (1982:6-7) outlines what he considers to be a productive approach to a "contextual" archaeology:

> Thus the primary goal of environmental archaeology should be to define the characteristics and processes of the biophysical environment that provide a matrix for and interact with socioeconomic systems, as reflected, for example, in subsistence activities and settlement patterns. The secondary objective of this and of all the contributing methods is to understand the human ecosystem defined by that systemic intersection...It is within this human ecosystem that earlier

> communities interacted spatially, economically, and socially with the environmental matrices...

In order to study Butzer's second objective we must apply employ theoretical concepts that are well-suited to the consideration of the "systemic intersection" between the biophysical and socioeconomic context of humans.

Towards a Model of Lower Salmon River Canyon Riparian Paleoecology

In order to address questions regarding technological, subsistence and settlement changes among LP-MH hunter-gatherers in the LSRC, an emphasis was placed on the collection of paleoenvironmental and geologic data that would provide insights into the natural context of these culture changes. Emphasis was placed on gathering information about the late Quaternary history of the canyon from several viewpoints and organizing these data in a manner that could be used to make statements about the changing nature of riparian ecosystems. Syntheses of conceptual and quantitative approaches to terrestrial ecosystems (e.g., Shugart 1998) and riparian ecosystems (e.g, Malanson 1993; Brown 1997) are available, yet often include categories and degrees of data resolution not available in paleoenvironmental records. Acknowledging this problem, Butzer (1982:19-20) states that,

> The complexities of even the rudimentary and partial systems sketched here serve to show that modern functional ecosystems are essentially impractical for empirical study. Not surprisingly, past ecosystems remain beyond reconstruction. However, for most ecologists, the ecosystem serves primarily as a paradigm, a broad conceptual approach in which to organize and interpret data. The environmental system has a similar focal and heuristic value in contextual archaeology.

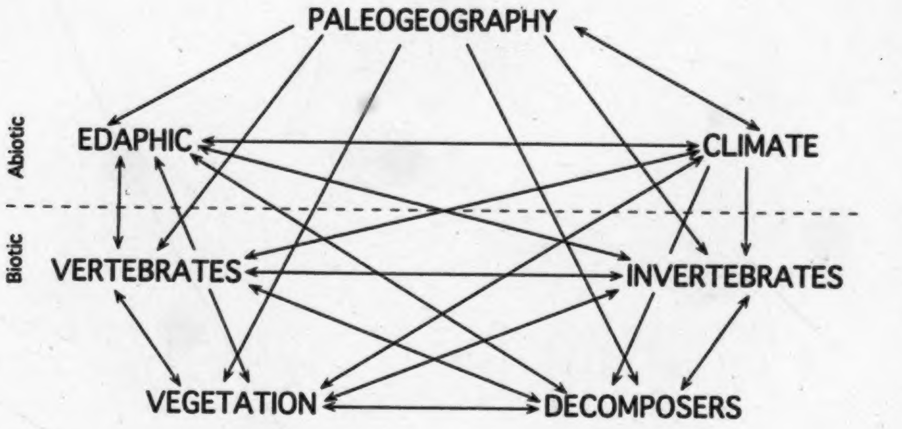
While Butzer warns us of the difficulties of approaching paleoecologcial reconstructions, particularly using quantitative approaches employed in studies of modern ecosystems, the use of the ecosystem concept remains useful, particularly as a guiding concept in a qualitative study.

The framework developed by Schweger (1990) to evaluate the last-glacial Beringian ecosystem was adopted for the development of a LSRC paleoecology model. Schweger identifies seven interconnected components of the Beringian ecosystem, including paleogeography, climate, invertebrates, decomposers, vegetation, vertebrates, and an edaphic aspect (soils). Qualitative assessments of the nature of each component and its influence on other aspects of the ecosystem are provided by considering a broad range of biotic and abiotic proxy datasets.

Using Schweger's model as a means of guiding the collection of necessary paleoenvironmental data, stratigraphic and geomorphological data, a geoarchaeological study was made in the LSRC with the goal of reconstruct the nature of geologic processes, environmental conditions, and landscape evolution through time (Figure 2). Proxy paleoclimatic records were built from locally-available sources and paleoenvironmental methods were developed to elucidate the changing spatial patterning of slope and riparian vegetation. Once collected, these datasets were assembled at complementary time scales in order to examine changes in canyon ecology during the late Pleistocene to middle Holocene. The resulting dataset provided interesting insights into the changing environmental context of the canyon and contributed information that has proven invaluable for the development of hypotheses about the role of riparian environments in the evolution of early Plateau hunter-gatherer sociocultural systems.

Methods of Data Collection and Analysis

The datasets required for the LSRC paleoecological model were gathered through various methods of fieldwork and laboratory analysis (Table 1). Brief discussion is provided below to clarify the data requirements and processses of collection that worked best for this study.


PALEOGEOGRAPHY
Abiotic
Biotic
EDAPHIC
CLIMATE
VERTEBRATES
INVERTEBRATES
VEGETATION
DECOMPOSERS

Lower Salmon River Canyon Riparian Ecosystem Model (12 - 6 ka BP)

Figure 2. Diagram showing the components and their interrelations that comprise the Lower Salmon River Canyon riparian ecosystem model (modified after Schweger 1990).

Field Approaches

Since late Quaternary paleoenvironmental and geologic information was nearly absent in the LSRC, a great deal of primary information was needed to build a model of past riparian ecology. These datasets were collected through various field and laboratory methods, described in the sections below.

Surficial Mapping

Fieldwork conducted during 1996 allowed for the mapping of surficial geology units along 17 river miles between White Bird Creek and American Bar in the LSRC. Surficial geology units were initially delineated from 1:24,000 and 1:6,000 scale color airphotos, and were later ground truthed along the entire stretch of the study area between 1997 and 2000. The construction of a surficial geology map represents a first step in the larger geoarchaeological evaluation of the late Quaternary record of hydrological changes and the evolution of canyon landforms. This work helped to identify the continuity of landform types and the distribution of various geologic deposits in the study area, and was useful for working out the geologic history and the larger paleoecological context of the canyon.

Stratigraphic Studies

The stratigraphic dimension of mapped surficial geology units was investigated through detailed work at existing and excavated geologic exposures. At each of the stratigraphic localities, data regarding the lithologic, sedimentary, pedologic, chronologic, and geochemical aspects of canyon sediments were recorded. In total, geologic information and samples collected from over 40 geologic sections and stratigraphic profiles at six archaeological sites contributed to a large dataset. Correlation between stratigraphic units was made by considering the presence of key deposits, radiocarbon dated samples, pedostratigraphic units, and elevation of deposits.

Geomorphic Mechanisms

The deposition, erosion, and alteration of surficial deposits was investigated through field descriptions and laboratory analyses. By considering the operation of different geomorphic processes through time, paleoenvironmental interpretations were strengthed, particularly where forcing mechanisms, such as climate change, could be tied to specific modes of sedimentation or erosional events. Evidence

Abiotic Components	Proxy Data
1. alluvial deposition, erosion, bedload, competency	lithostratigraphic, pedostratigraphic, and allostratigraphic units
2. rates of precipitation	stable isotope geochemistry of mollusk shell carbonate
3. alluvial channel gradient	terrace and allostratigraphic elevations
4. alluvial discharge	stable isotope geochemistry of soil and mollusk shell carbonates; lithostratigraphy
7. floodplain geometry	lithostratigraphic, pedostratigraphic, allostratigraphic units and surficial deposits mapping
8. annual temperature and evaporation	stable isotope geochemistry of soil carbonates

Biotic Components	Proxy Data
1. vegetative composition and distribution	carbon-13 record of soil carbonate
2. faunal composition	faunal remains in sites
3. habitat productivity and distribution	review of paleoclimate and autecological requirements of plant and animal species

Table 1. Organizational framework for required paleoecological data and its interpretation for the Lower Salmon River Canyon.

compiled from a consideration of landform geometry, sedimentological structures, granulometry, clastic sorting, clastic morphology, and the nature of stratigraphic boundaries were used to interpret the genetic nature of deposit formation and alteration.

Laboratory Analyses

Paleoclimatic and Paleovegetation Studies

A perspective on regional and local paleoclimatic conditions was needed to best reconstruct the relationship between inputs and outputs in the LSRC hydrologic and geomorphic systems. Evidence of paleoclimatic and paleovegetation conditions in the LSRC was sought from several lines of evidence available in the study area, including: stable oxygen and carbon isotope geochemistry of soil carbonates; grain size distribution within aeolian sediments; and, stable oxygen and carbon isotope geochemistry of river mussel shell carbonate from several archaeological sites.

Archaeological Data Collection and Treatment

Archaeological excavations were conducted at seven sites between 1997 and 2000, involving field school students from the University of Alberta and the University of Idaho. These include the Cooper's Ferry (10IH73), McCulley Creek (10IH1160), American Bar (10IH395), Bug Slope (10IH1220), Rock Creek Bridge (10IH2491), Gill Gulch (10IH1308), and Nipehéme Village (10IH1312) sites. Because the size of the crew was typically small (from 3 to 18 persons per site), and care was used to recover large quantities of archaeological materials *in situ*, only a small portion of any given site could be investigated during the limited time available each field season. Reference baselines and excavation units were established relative to true north with a theodolite. Excavation units took the form of 2 x 2 meter or 1 x 2 meter pits. Excavators employed tools and methods best suited for the particular goals at hand, including pick and shovel work in extremely rocky matrices, skim shovelling with sharpened square nose shovels in finer sediments, detailed excavation with trowel and dustpan, and occasionally, when needed, extremely careful excavation with wooden modelling tools or dental picks. Arbitrary 5, 10, and 20 cm levels were maintained at all sites, depending on the particular situation, except for Gill Gulch, where excavation of 10 and 20 cm levels followed natural stratigraphic units for the majority of the time. Elevation of excavation levels and finds was measured with reference to a string and line level tied to datum pins positioned at the highest corner of each excavation unit. Excavated sediments from each level were passed through wire mesh screen cloth with various apature dimension including 1/4", 1/8" and 1/16". Screening was always conducted through 1/8" screen cloth, while only samples of sediment were processed through 1/16" screen cloth. Water screening was employed through nearly all of the 2000 excavations at Gill Gulch and involved pumping water from the river through garden hoses with spray nozzles to process sediment through 1/8" screen.

During much of the excavations at Cooper's Ferry, Nipeheme Village, McCulley Creek, and in portions of the Gill Gulch site, efforts were made to establish the three-dimensional position of those artifacts and faunal materials with surficial area greater than 1 cm^2 in order to establish a detailed provenience database that might be used in spatial analyses. All artifacts and faunal materials were either bagged and recorded individually (with their associated proveneince information) as they were encountered, or they were placed into a level bag without precise three-point provenience. In either case, all materials recovered from given level or feature were ultimately placed in a corresponding level or feature bag. Standardized forms were filled out at the completion of each level or feature, and notes were maintained by site and unit supervisors. Photographs and sketches were made of level floors following completion of each level. All artifacts were taken to the field laboratory where they were cleaned, sorted, measured, recorded, given a unique catalog number (either written on the artifact itself and/or on its corresponding bag), and entered into a catalog database. Photographs, digital images, and illustrations of individual artifacts were also made.

Summary and Conclusions

Darwinian theory will be employed to help explain changes in the archaeological record that correspond to the Paleoarchaic-Archaic transition in a scientific manner that accounts for evolutionary processes. Since selective pressures that operate on human behavior often originate in the environmental setting in which the behaviors are used, the character and changing conditions of LP-EH riparian ecosystems will be studied as well. The natural context of the Paleoarchaic-Archaic transition will be established by collecting data that can address environmental components presented in a model of LSRC riparian paleoecology. By comparing the material record of human behavior against the ecological context in which they are found, it will be possible to generate explanations for the observed changes in the archaeological record of the Paleoarchaic-Archaic transition.

The results of LSRC riparian paleoecology studies will be reserved for Chapter Six, where they follow the presentation of primary enviromental data in Chapters Three through Five. This will help to maintain a linear flow in the text throughout the study and will hopefully enhance its readibility and cohesiveness.

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CHAPTER THREE

LATE QUATERNARY GEOLOGY OF THE LOWER SALMON RIVER CANYON, IDAHO, BETWEEN HAMMER CREEK AND AMERICAN BAR

A version of this chapter by L.G. Davis is being considered for publication by the Idaho Geological Survey

Introduction

A geologic study of late Quaternary surficial deposits in the Lower Salmon River Canyon was conducted between 1996 and 2000 in order to achieve several goals. First, this work was funded as part of a challenge cost share agreement between the Bureau of Land Management and the University of Alberta in order to develop a stratigraphic and paleoenvironmental framework that might be applied in regional archaeological research. Second, the assembled geologic database represents a portion of the evidence used by the author in dissertation research, which sought to offer a new archaeological explanation for the Paleoarchaic-Archaic cultural transition of the southern Columbia River Plateau.

Boundaries of the Study Area

This study is limited to those areas of the Lower Salmon River Canyon downriver of Hammer Creek (river mile (RM) 53) and to the downstream end of American Bar (RM 36) (Map 1), below an elevation of 550 m above sea level (masl) (1,800' above sea level (asl)). A greater emphasis was placed on the study of surficial deposits and landforms located along the Salmon River, than was given to those contained in tributary canyons.

Geologic Time

Geologic deposits encountered in the Lower Salmon River Canyon date to the last 240 million years, comprising many divisions of geologic time (Table 2). Predominantly, this study will address the unconsolidated sediments found in the canyon, which fall entirely within the Quaternary Period and its Pleistocene and Holocene Epochs. In the sections that follow, geologic time will be discussed in several ways, relating to both scales and methods of measuring time. Radiocarbon dates are reported in uncalibrated ^{14}C years before present, along with their one-sigma standard error (e.g., ±90 yr BP), and laboratory identification number (e.g., Tx-9137). Ages established by other chronometric means will be reported in either millions of years ago (ma) or thousands of years ago (ka).

Era	Period	Epoch	Approximate Age in Millions of Years Before Present
Cenozoic	Quaternary	Holocene	.01
		Pleistocene	2
	Tertiary	Pliocene	5
		Miocene	24
		Oligocene	38
		Eocene	55
		Paleocene	63
Mesozoic	Cretaceous		138
	Jurassic		205
	Triassic		240

Table 2. Geologic time scale relevant to the stratigraphy of the Lower Salmon River Canyon (adapted from Plummer and McGeary 1982).

Methods of Data Collection

In order to gather information that might be used to form a stratigraphic record of Quaternary deposits in the Lower Salmon River Canyon, pedostratigraphic, lithostratigraphic, and chronostratigraphic information (NACOSN 1983) was gathered from many points along the river. Geological mapping of study area surficial deposits was conducted by using 1:24,000 and 1:6,000 scale color airphotos, and extensive groundtruthing. Stratigraphic localities present in mapped landform units were sought during ground surveys so that a basis for canyon-wide comparison and chronological ordering of geological deposits could be developed. By establishing study sections, a reference system was developed wherein specific stratigraphic units defined for the development of a Salmon River Canyon paleoenvironmental and paleolandscape record could be formally described and defined. These formal sections can be revisited by others seeking to explore or reevaluate the nature of the local geology first hand.

At each of the stratigraphic localities several kinds of data were recorded. This recording process involved: (1) cleaning the section to reveal the stratigraphy of the locality; (2) the creation of stratigraphic drawings, showing the geometric form and spatial relationships of sedimentological deposits, pedological development, fossil inclusions and archaeological features, as observed--as the sections were drawn, preliminary stratigraphic units were defined on the basis of distinguishing criteria (e.g., color, depth of pedogenic development, unit boundaries, lithological content); (3) photographing the exposure from perspectives that show the stratigraphic units at an overall and individual scale; and (4) the description of the physical characteristics exhibited in each stratigraphic unit.

Soil descriptions made in the field follow guidelines set forth by the U.S. Soil Conservation Service (Soil Survey Division Staff 1993) and Birkeland (1984). Data collected include soil color, texture, consistence, presence and nature of clay skins, carbonate development, structure, and boundaries between soil units. Clast roundness was typically described in the field, following Folk (1955). Magnetic susceptibility of sediments was recorded with a portable Bartington MS2 susceptibility meter equipped with an MS2F probe, which was operated at a frequency of 0.58 kHz. Granulometric determinations were made in the laboratory in the following manner: 100.0 g samples of sediment were disaggregated by hand, using a mortar and pestle when needed, oven-dried (60° C (140° F)) for 24 hours, and poured into a stack of wire mesh sieves (U.S. Standard Sieve sizes 5, 10, 35, 60, 120, 230, and Pan), which were mechanically shaken for 15 minutes; afterwards, the contents of each sieve was weighed. Dry sieving was favored over a hydrometer method since LSRC sediments were typically dominated by sand-sized clastic fractions (which are measured more accurately with dry sieves), and possessed little (if any) clay in most cases.

Organization of Study

The approach taken in this study reflects the intended use of its results. The geographic and environmental context of the study area is presented, followed by a review of regional geology, particularly that dealing with the Quaternary, provides a suitable background. The results of this geologic study are presented next, in a manner that reflects the temporal context, general physical characteristics, and environmental implications of late Quaternary surficial deposits in the study area; particularly in the lower elevations of the canyon. Results are organized under genetic categories based on their sedimentological origin (e.g., alluvial, aeolian, and mass movement deposits), and include information on the descriptive characteristics, distribution, origin, age, and pedogenic alteration of indvidual deposits. A summary of the geologic history of the study area is followed by discussion addressing the nature and timing of late Quaternary geomorphic processes and environmental change.

Geographic and Geologic Setting of the Study Area

Physiography of the Modern Lower Salmon River Canyon

The headwaters of the Salmon River begin in the Salmon and Bitterroot Mountains of central and eastern Idaho (Figure 3), which rise above elevations of 3088 masl (10,000'asl). Tributaries of the Salmon River include the Lemhi River, the Pahsimeroi River, the South, Middle, and East Forks of the Salmon River, and the Little Salmon River. These tributary streams flow north and west, through granitic and metamorphic bedrock terrains of the Idaho Batholith. At Riggins, Idaho, the Salmon River turns north into a broader canyon. From this point, the Salmon River passes through sedimentary rock units of the Seven

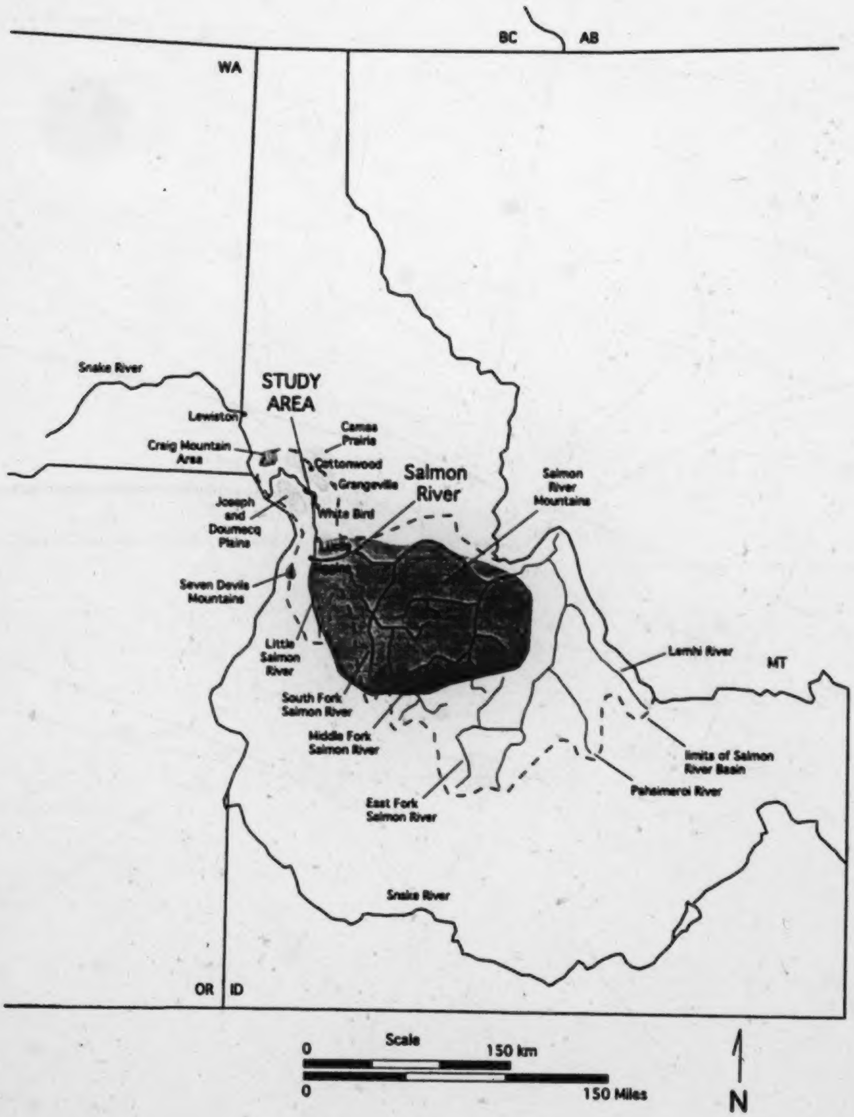
BC
AB
WA
Snake River
STUDY AREA
Lewiston
Craig Mountain Area
Camas Prairie
Cottonwood
Grangeville
Salmon River
Salmon River Mountains
White Bird
Joseph and Doumecq Plains
Seven Devils Mountains
Little Salmon River
Lemhi River
MT
South Fork Salmon River
Middle Fork Salmon River
limits of Salmon River Basin
Pahsimeroi River
East Fork Salmon River
Snake River
OR
ID
Scale
0
150 km
0
150 Miles
N

Figure 3. Location of study area in relation to geographic features mentioned in text. Shaded portions mark major physiographic areas mentioned in text (e.g., Salmon River Mountains).

Devils Formation and along the boundary of the Batholith and the Columbia River Basalts. Downstream from White Bird, the Salmon River Canyon cuts through metavolcanic and volcanic bedrock units as it winds its way to the Snake River, which flows into the Columbia River and on to the Pacific Ocean.

The Lower Salmon River Canyon begins at the confluence of French Creek on the main stem of the Salmon River, about 20 miles upstream from Riggins, downstream to where it joins the Snake River. Above Riggins, the Salmon River is entrenched in narrow, steep-walled canyons cut into the granitic bedrock of the Idaho Batholith. Downstream from Riggins many portions of the canyon are wider, with more gentle slope gradients, but tight and narrow canyons can still be found in areas with metamorphic bedrock (Figure 4). Canyon width appears to be directly related to the resistance of bedrock units to the erosional action of the river. Between Riggins and White Bird, the Salmon River flows through mountainous terrains adjacent to the Salmon River Mountains to the east and the Seven Devils Mountains complex to the west. Below White Bird, the Salmon River is flanked by large upland plateaus. The Camas Prairie lies to the north and east of the river, and the Joseph and Doumecq Plains are located to the south and west. Near the lower portion of the Salmon River, close to its confluence with the Snake, high relief terrains of the Craig Mountain area rise to the north.

Unilike most of the major rivers of the West, the Salmon River was not been impounded by hydroelectric dams, making it the longest free-flowing river in public ownership in the United States. Miners processed Salmon River surficial deposits with hydraulic placer mining methods in search of gold during the latter decades of the 19th Century and into the 20th Century. These activities left their mark on the Salmon River landscape. In some areas, where hydraulic mining was extensive, entire landforms may be missing. Because of the magnitude of these mining events, hydraulic placer mining assisted in the investigation of Salmon River Canyon geology. The erosional cuts left behind by placer miners provide many exposures from which geologic information was gathered.

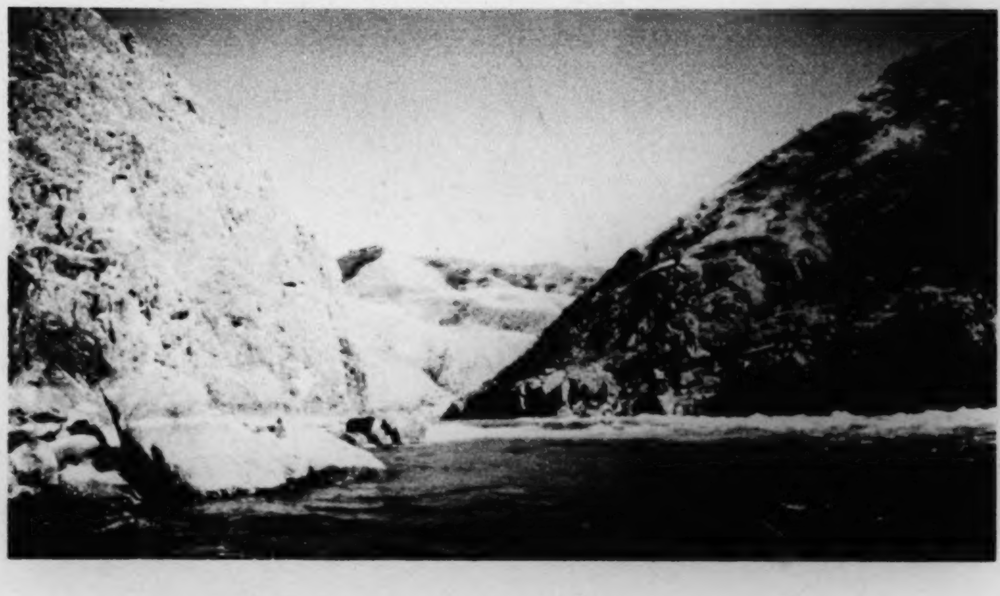

Figure 4. Photograph of Green Canyon as viewed from a boat at RM 43.2. Note steepness of metamorphic bedrock canyon walls and absence of surficial deposits.

Climate

Mean annual precipitation is varied in the basin. The bottom of the Lower Salmon River Canyon receives 42.7 cm (16.8") of rainfall and 18.8 cm (7.4") of snowfall, as measured at Riggins. Higher elevations receive greater amounts of precipitation. Warren, Idaho averages 67.3 cm (26.5") of rainfall and 418.8 cm (164.9") of snowfall annually, while an average of 57.1 cm (22.5") of rainfall and 85.9 cm (33.8") of snowfall is reported from Cottonwood. Mean maximum and minimum temperatures vary from 19.2° C (66.3° F) to 5.5° C (41.9° F) in lower elevations of the basin, and 10.9° C (51.4° F) to -6.2° C (21.0° F) in the higher elevations (Western Regional Climate Center 1999).

Hydrology

Annual discharge of the Salmon River is largely controlled by the melting of accumulated snowpack in the upper reaches of the basin. Of greater influence than rainfall, the annual melting of the snowpack controls annual rates and timing of alluvial discharge values. In his overview of the environmental setting of the Lower Salmon River, Sisson (1985) characterizes its modern alluvial behavior in the following manner: As measured at the White Bird gauging station, the mean annual discharge of the river is 302.7 cubic meters per second (cms) (10,690 cubic feet per second (cfs)). Maximum discharge was placed at ca. 3681.6 cms (ca. 130,000 cfs), while the lowest measured flow lies at 44.8 cms (1,580 cfs). Averaging 1897.4 cms (67,000 cfs), peak flow typically occurs between May and June as rising spring temperatures and rain-on-snow events melt the snowpack. By September, Salmon River discharge is at its lowest point. River flow remains subdued throughout the fall and winter months.

Vegetation

The Lower Salmon River Canyon is inhabitated by subalpine forests and semi-arid shrub grasslands in its more mesic upper elevations, and predominantly semi-arid shrub grasslands in the lower reaches, where it receives more warmth and less precipitation. Small, scattered stands of Ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*) are found at the higher reaches of the canyon, on north- and west-facing slopes and in stream drainages. Historically, the lower canyon slopes supported a cover of native grasses (e.g., bluebunch wheatgrass (*Agropyron spicatum*)), annual bromes (*Bromes tectorum, B. japonicus, B. brizaeformis, B. commutatus, B. rigidus*), and other leafy plants including arrowleaf balsamroot (*Balsamorhiza sagittata*) and yarrow (*Achillea millefolium*). Tributary drainages with annual or seasonal streamflow and on east and north-facing slopes typically contain thickets of various shrub species (e.g., hackberry (*Celtus douglasii*), smooth sumac (*Rhus glabra*), ninebark (*Physocarpus malvaceous*), mountain mahogany (*Cercocarpus ledifolius*), hawthorn (*Crataegus douglasii*)) and isolated stands of ponderosa pine (*Pinus ponderosa*) and douglas fir (*Pseuduotsuga menziesii*).

Previous Research: Triassic to Tertiary geology

During the Cretaceous, exotic terranes collided with western Idaho, at what was an ancient continental margin (Alt and Hyndman 1989). These exotic formations include igneous, metamorphic and sedimentary lithologies, and are considered to represent marine and Pacific island rocks formed during the Triassic (Vallier 1977). Accreted terranes are extensive in an area extending east from the Wallowa Mountains of northeastern Oregon to the Seven Devils Mountains region of west-central Idaho and comprise the larger Wallowa-Seven Devils Arc Terrane region. Exposures associated with these accreted terranes are commonly seen in the Lower Salmon River Canyon between Riggins and White Bird, and in the bottoms of deeply-cut canyons downstream.

Ross (1938) named the Martin Bridge Formation on the basis of Triassic (220 million years (ma)) limestone deposits seen across the Wallowa-Seven Devils Arc Terrane region. In the Lower Salmon River Canyon, limestone attributed to this formation is visible near Lucille and upstream of the Slate Creek Guard Station (Gaston and Bennett 1979). The Riggins Group includes a series of metamorphic rock units predating 100 ma, which form arc and forearc basin terranes (Hamilton 1963; Coffin 1967). These units occur along the Western Idaho Suture Zone and were formed during previous subduction along an ancient continental margin. Lithologies include serpentinite, talc, schist, graphite, shale, and flysch. These metamorphic rocks are thought to be derived from Seven Devils Complex lithologies (cf. Ptacek 1965; Vallier 1977).

The Atlanta Lobe of the Idaho Batholith is comprised of granite to granodiorite formed during the late Cretaceous between ca. 65 to 85 ma (Maley 1987) and is linked to the subduction of accreting terranes. As these terranes collided with the Cretaceous coastal margin they were subducted beneath the continental plate, creating an area of metamorphic alteration termed the Western Idaho Suture Zone. The boundary of the Western Idaho Suture Zone is marked by rocks that show considerable folding and gneissic lithology (Hamilton 1963; Coffin 1967; Onasch 1977). Downstream from Riggins, the Lower Salmon River runs northward along the edge of this suture zone.

Extensive layers of basalt are commonly seen in the walls of the Lower Salmon River Canyon. These layers represent five episodes of Tertiary volcanic activity, which extruded from deep fissures that trended north to northwest along the eastern edge of the Columbia Plateau (Holden 1974; Reidel 1978). These volcanic layers are named the Saddle Mountain Basalt (6.0 - 13.5 ma), the Wanapum Basalt (13.5 - 14.5 ma), the Grande Ronde Basalt (14.5 - 16.5 ma), the Picture Gorge Basalt (16.5 ma), and the Imnaha Basalt (16.5 - 17.5 ma) (Maley 1987). Together, the maximum thickness of these basalt units is ca 2500 m (ca. 8,200') (Hooper and Swanson 1990). Basalts flooded into topographically-low areas, eventually producing plateaus seen today in west-central Idaho. Evidence of older terranes can be seen beneath the basalts in deep canyon exposures. As Columbia River Basalt flows infilled river canyons during Miocene times, alluvial flow became impounded, producing large lakes in many areas of west-central Idaho. Fine sediment accumulated in these lakes is preserved between basalt units, as a result of being capped by later lava flows. The sands and silts of the Latah Formation occasionally produce floral and insect fossils. In some areas, basalts overlie silica-rich tuffs or tephras, and produced contact-metamorphosed chert deposits.

Previous Research: Local and Regional Quaternary Geology

Of the handful of studies that address the geology of the Lower Salmon River Canyon, very little research deals with Quaternary-age deposits. The few Quaternary geologic studies conducted include an investigation of gravel bars near Slate Creek and at China Bar, located 0.8 km (0.5 miles) below the mouth of China Creek (Webster et al. 1982), and sediments contained in the Cooper's Ferry site (Butler 1962, 1969) and Weis Rockshelter (Butler 1962). In both of these studies, Butler reported descriptions of sediments and soils, and made attempts at linking geologic depositional events with paleoclimatic conditions. Welford (1988) made a study of unconsolidated terrace deposits along the Little Salmon River, which flows into the Lower Salmon River near Riggins, Idaho. Other limited stratigraphic studies have been conducted as part of archaeological excavations along the Lower Salmon River (e.g., Markos et al. 1990; Miss et al. 1990; Davis et al. 1995; Sappington et al. 1995); however, this work was restricted to deposits dating to the last 4,000 yr BP or so. Thusfar, a comprehensive study of late Quaternary surficial deposits in the Lower Salmon River Canyon has not been conducted.

Glaciation

During the Wisconsinan glacial period and into the Holocene, glaciers grew in mountain cirques and alpine valleys of the Salmon River, Bitterroot and Clearwater River Mountains of central Idaho (Knoll 1977; Butler 1984a, 1984b, 1986; Colman and Pierce 1986; Cotter et al. 1986; Cluer 1987) and in the nearby Wallowa Mountains of northeastern Oregon (Kiver 1974; Burke 1978). Farther to the north, the Purcell Trench Lobe of the Cordilleran ice sheet advanced as far south as Lake Pend Oreille between 25 and 13 ka (Richmond 1986). Clague (1978, 1981) identifies an ice-free interstadial period in northern Idaho at 17 ka. In order to support Waitt's (1985) claim for the existance of glacial Lake Missoula between 17 and 11 ka, however, the Purcell Trench Lobe must have had already advanced into the Pend Oreille basin past the mouth of the Clark Fork River during Clague's interstadial time (cf. Breckenridge 1989).

The glacial chronology of the Salmon River basin is poorly known compared with other Pacific Northwest areas. Butler (1984a, 1984b, 1986) places the timing of the latest glacial retreat in east-central Idaho's Lemhi Range at a time prior to 11,200 due to the presence of Glacier Peak set B tephra in alpine meadow sediments. Butler (1984a, 1986) also interprets late Pleistocene to early Holocene glacial activity from reported periglacial wedges and deformed bedding structures dated between 10,130 yr BP and 7,560 yr BP. Cotter et al. (1986) use Glacier Peak set B tephrochronology to limit the timing of glacial retreat in the Pioneer Mountains of central Idaho before 11,200 yr BP.

Numerous studies describe glacial deposits in various parts of the Salmon River basin and along its periphery, including the Seven Devils Mountains (Cook 1954), near McCall, Idaho (Colman and Pierce 1981), in the Burgdorf area--east of the Little Salmon River and south of the Salmon River--Capps (1940) identified evidence of multiple glaciations, interpreted as Wisconsinan to pre-Wisconsinan in age, which formed Idaho's largest mountain glacier complex. Central Idaho glacial ice coalesced into large mountain glacier complexes, restricted to the upper elevations of river basins. While these glacial events would undoubtedly influence the hydrology of the Salmon River, a clear chronological framework for central Idaho glacial activity is lacking at this time. Thus, it is difficult to compare evidence of alluvial behavior to glacial conditions in the Salmon River basin at a meaningful level.

Pleistocene Floods

Two major sources of catastrophic Pleistocene flooding affected the southern Columbia River Plateau region. The first flood originated from overflow of Glacial Lake Bonneville, which stood in the modern basin of the Great Salt Lake of Utah and into adjacent areas of eastern Nevada (Malde 1968). Massive overflow of Lake Bonneville occurred through Red Rock Pass, near Pocatello, Idaho at about 14,500 yr BP (O'Connor 1993). Bonneville Flood waters spread across the Snake River Plain of southeastern Idaho and down the Snake River canyon. Floodwaters deposited gravel to an elevation of 500 masl (1640' asl) at Pittsburg Landing in Hells Canyon (Cochran 1991) and in other areas along the Snake River (Webster 1980; Webster et al. 1982).

The second flood was identified by Bretz (1929) as originating from the Missoula basin of western Montana. As the Purcell Lobe of the Cordilleran ice sheet moved south into northern Idaho, the drainage of the Clark Fork River was impeded. As a result, "the world's largest ice-dammed lake" (Alt and Hyndman 1989:62) (ca. 600 m (ca. 2000') deep) formed in the Missoula basin. During what is interpreted as at least 17 separate flood events (Webster et al. 1982; cf. Waitt 1980), catastrophic amounts of water burst forth across northern Idaho and eastern Washington producing immense erosional and depositional features (Bretz 1929; Lupher 1945; Hammatt 1976; Webster et al. 1976; Baker 1973; Waitt 1980, 1984, 1985; Bunker 1982; Baker et al. 1987; Breckenridge 1989). Evidence of the Missoula floods can be traced at an elevation of 350 masl (1,150' asl) in the Pasco Basin of eastern Washington and adjacent areas (Bretz 1929; Waitt 1980) and up to ca. 400 masl (1,300' asl) in the area of Lewiston, Idaho (Bretz 1925; Lupher 1940, 1944). Rhythmite deposits associated with the Missoula Floods were dated between 15,000 and 12,000 yr BP in the Lewiston Basin of western Idaho (Webster et al. 1982:679). Webster et al. (1982:Figure 1) report, "eight rhythmites, each lacking an easily defined basal part (consisting only of medium sand), are present along the lower Salmon"; the existence of a "back-eddy bar" is shown as occurring less than 16 km (10 miles) from the Salmon-Snake confluence, but is identified (perhaps mistakenly?) as a Bonneville Flood Deposit.

Volcanic Tephra-Falls

Multiple layers of Quaternary-age volcanic tephra are found in the Pacific Northwest, produced during plinian eruptions of Cascade Range mountains. The distribution of late Pleistocene and Holocene tephra layers are better known and are mapped by Shipley and Sarna-Wojcicki (1983) (see also Davis 1995:Figure 3). According to their map, several tephras might be expected to occur in the Lower Salmon River Canyon area. These tephras include: Glacier Peak set B, which erupted at ca. 11,200 yr BP (Mehringer et al. 1977, 1984; Porter 1978) from Glacier Peak in the Northern Cascades of Washington; Mazama set O, which erupted from current-day Crater Lake between ca. 6,600 yr BP (Fryxell 1965) and 6,850 yr BP (Bacon 1983; Sarna-Wojcicki et al. 1991); Mount St. Helens Ye, which is found in eastern Washington and northeastern Oregon, was erupted at ca. 3,350 yr BP (Mullineaux et al. 1975). Other older eruptions are known to extend eastward from Cascade Range volcanoes, including Mount St. Helens sets J and S (dated between 13,000 to 11,000 yr BP) (Mullineaux 1986), set K and M (dated between ca. 18,000 and 21,000 yr BP) and set C (dated between ca. 36,000 and <50,000 yr BP) (Crandell 1987) the Llao pumice from central Oregon Cascade Range (dated between ca. 60,000 and 70,000 yr BP (Sarna-Wojcicki, written communication 1999)) and the Bend Pumice, which is widespread in central Oregon (dated between ca. 350 and 400 ka (Sarna-Wojcicki, written communication 1999)). The areal distribution of these older eruptive sets are not as well known as other younger Cascade Range volcanic tephras (Shipley and Sarna-Wojcicki 1983).

Alluvial Geology

Little Salmon River

Welford's (1988) study of alluvial fans, terraces and erosional platforms along the Little Salmon River, which flows into the Lower Salmon River at Riggins provides one of the few examples of

Quaternary geology in the Salmon River basin. Welford stresses the influence of local non-synchronous mass movement and alluvial fan aggradation events as important forcing mechanisms responsible for the character of Little Salmon River Valley alluvial deposits; and de-emphasizes the role of Quaternary climates in shaping the local geologic record.

Lower Granite Reservoir

Hammatt (1976:72-94) identifies three different alluvial deposits in the Lower Granite Reservoir of the Lower Snake River Canyon that relate to fluvial activity during the Holocene. The first, named the Early Alluvium (Qae), dates between 10,000 and 8,000 yr BP and is characterized by indistinct beds of loamy sand to silt loam, contains pedogenic carbonate, varying degrees of soil develoment and lies up to 23 m (75') above the Snake River channel. The Early Alluvium is interpreted as forming during conditions of either higher fluvial discharge or when the Snake River channel was positioned at a higher elevation than today. Erosion of this deposit apparently occurred after 8,000 yr BP but before 6,700 yr BP, from a combination of aeolian and slopewash processes (Hammatt 1976:78).

The Middle Alluvium (Qam), is found on a low terrace in the Lower Granite Reservoir. Deposition of this unit is dated between 4,000 to 2,500 yr BP (Hammatt 1976:89). Seen as numerous weak beds of very fine sandy loam to loamy sand, totalling three or more meters thick, the Qam is similar in appearance to the Early Alluvium; however, the Qam may be differentiated from the older unit by its darker color. The Middle Alluvium is found up to 10 m (33') above the Snake River channel and is thought to, "represent a shift in geo-hydrological conditions of the Snake River resulting in seasonal aggradation at lower levels than the early alluvium" (Hammatt 1976:90).

Lastly, Hammatt identifies the Modern Alluvium (Qal), which is found at lower elevations (up to 7 m (23')) above the Snake River channel, and appears as unbedded fine sand bars and well-bedded sandy loam in higher, better vegetated reaches. No quantitative age estimate is given for this unit, other than a mention of the inclusion of reworked late prehistoric and historic cultural materials within the deposit (Hammatt 1976:94).

Clearwater River

In his study of the early lithic technology of cultural occupation at the Hatwai site (10NP143), Sanders (1982) provides a description of the geologic sequence seen during excavations. The Hatwai site is located along the lower Clearwater River, about five miles from its confluence with the Snake River, near Lewiston, Idaho. Sanders (1982:30-41) describes four geologic units, which are further divided into 10 units that represent, "lateral facies changes of the major units" (Sanders 1982:Table 3, pg. 25). The basal unit encountered at the Hatwai site, named the Lower Gravels, includes a coarse sand (Unit 7) with loose consistency and evidence of oxidation, overlain by a pale brown coarse sand (unit 6B) with limited bedding (in the form of lenses), which was in turn partially capped by gravels (unit 6A) containing Unit 5 interstitial fill. Charcoal samples collected from Unit 7 provided a date of 10,820 ±140 yr BP (Tx-3159). A series of silt, gravel and sand deposits comprise Sanders' Intergravel Lens and Upper Gravels units (including unit numbers 5-2A). These units were capped by alluvium designated as QAE (unit 1), characterized by intercaled beds of sand and silt. The QAE unit contained two radiocarbon dates of 8,800 ±310 yr BP (Tx-3265) and 9,160 ±230 yr BP (Tx-3086) and are correlated temporally, at least, with Hammatt's (1976) Early Alluvium (10,000 to 8,000 yr BP) (cf. Fryxell and Keel 1969; Fryxell et al. 1968; Rice 1972; Leonhardy 1970).

Sanders (1982: Table 5, pg. 38) interprets this stratigraphic sequence to reflect alluvial processes and depositional environments that range from low energy contexts producing fine sediment drapes over gravels or periods of non-deposition, medium-energy contexts that removed fine sediments and lagged cultural materials on gravel surfaces, to high-energy situations that introduced coarse clastic material and/or eroded surficial deposits. This interpretation of depositional events at the Hatwai site points to a considerable degree of alluvial floodplain instability along the lower Clearwater River during the late Pleistocene to early Holocene.

Aeolian Sedimentation

Weis Rockshelter

Butler (1962) interprets aeolian processes as dominating sedimentation in Weis Rockshelter--which is located in the Lower Salmon River basin--between ca. 7,500 yr BP and 3,500 yr BP. The presence of diatom shells and sponge spicules in the aeolian deposits leads Butler (1962:24) to conclude that the, "...sediment may have been originally deposited in a moist environment and then subsequently redeposited under drier conditions."

Palouse Records

Wind-blown sediments are well-studied in the Palouse region of eastern Washington, situated to the northwest of the study area. McDonald and Busacca (1992) and Busacca and McDonald (1994) present a generalized summary of late Quaternary loess deposition and soil formation from the Channeled Scabland region of eastern Washington. Three periods of loess deposition, informally named L1, L2 and the "older loess" are seen to span nearly 55,000 yr BP. These loess units are separated by early and late Wisconsinan flood events, dating between ca. 48,000 (?) - 45,000 (?) yr BP and ca. 19,000 - 15,000 yr BP, respectively.

Lower Granite Reservoir

Hammatt (1976:97) identifies several aeolian deposits in the Lower Granite Reservoir of the Lower Snake River Canyon. The oldest of these is the pre-ash aeolian sand, which is dated between 8,500 and ca. 6,800 yr BP. Next, the ash rich loess is dated between ca. 5,750 and before 4,500 yr BP and is followed by the brown loess, which dates from 4,500 to 4,000 yr BP. The last two units include the aeolian sand II, which dates between ca. 1,500 and 750 yr BP, and the aeolian sand I, which covers the period of 750 to ca. 0 yr BP.

Pedostratigraphy

Palouse Records

During the deposition of Palouse loess units, five pedostratigraphic units formed (Busacca et al. 1992; McDonald and Busacca 1992; Busacca and McDonald 1994). The first of these is named the Devils Canyon Soil, which is always found beneath the Mount St. Helens set C tephra (ca. 36,000 - 42,000 yr BP (Mullineaux 1986)), and is identified by the development of an upper cambic horizon with weak columnar or subangular blocky structure, and moderate to high percentages of carbonate nodules that increase with depth into a characteristic petrocalcic horizon. Next, the Old Maid Coulee Soil dates to just after the eruption of the Mount St. Helens set C tephra. This soil is notably weaker than the previous pedostratigraphic unit, and is represented by a cambic horizon, weak columnar and subangular blocky structure, and poorly-developed calcic horizons comprised of filaments and dispersed carbonate in the matrix. Marked by its characteristic light-gray petrocalcic horizon, the Washtucna Soil lies immediately below the Mount St. Helens set S tephra (ca. 13,000 yr BP (Mullineaux 1986)). This soil includes a weakly to strongly cemented Bkqmb horizon with high percentages of cemented nodules. Vertical and horizontal seams of carbonate penetrate lower horizons, which eventually grades into structureless loess with few nodules. The Sand Hills Coulee Soil is found beneath the Mazama O tephra (ca. 6,700 yr BP) with weakly developed Bwkb1 and Bkb1 horizons. Lastly, a modern soil occurs at the surface of loess profiles in eastern Washington and includes columnar and blocky structure, but lacks the robust petrocalcic and nodule-bearing horizons of paleosol units.

Lower Granite Reservoir

Four soil units dating within the last 8,000 radiocarbon years altered surficial deposits of the Lower Granite Reservoir (Hammatt 1976). From oldest to youngest, these date between 8,000 to ca. 7,500 yr BP (soil 1), 5,000 to ca. 4,500 yr BP (soil 2), 2,500 to 1,500 yr BP (soil 3) and within the last century or so (soil 4). The first soil is seen in the upper portion of the Early Alluvium, identified by its B horizon characteristics, and appears to be one of the better-developed soils in the reservoir area (Hammatt 1976:73). The second soil developed on the Ash Rich Loess unit and includes weak soil color and structural B horizon development, with moderate medium prismatic structure and notable calcium carbonate content (Hammatt 1976:87). The third soil is found developed into the Middle Alluvium, denoting a period of non-deposition. This soil is weakly developed, with a calcareous structural B horizon represented by moderate medium columnar to moderate medium blocky structure. Soil 4 is identified as having formed under modern environmental conditions and is rather weakly developed compared to other soil units (Hammatt 1976:97).

Structural Adjustment of Bedrock Units

Gaston and Bennet (1979) report the positions of several known fault lines in the Grangeville quadrangle. Structural adjustment of bedrock units in the Lower Salmon River Canyon is dominated by dip-slip block movement and thrust faults. In the study area, faulting is restricted to dip-slip block movement. The position of known fault lines and their respective directions of movment are superimposed on a surficial geology map of the study area (Map 1). Vertical displacement of bedrock units in the Lower Salmon River Canyon undoubtedly influenced rates of alluvial downcutting and deposition in various areas through time. The presence of several upthrown and downthrown blocks between the mouth of White Bird Creek and Diamond Drill Canyon (at ca. river mile 50.6) may explain the local presence of thickly-bedded alluvial fans and the preservation of alluvial terraces in the area. Further downstream, a fault line between an upthrown and downthrown block runs adjacent to the origin of the Devils Garden Slide block. Movement along this fault line likely induced the mass movement that distributed Devils Garden Slide diamict into the canyon bottom.

Timing of Canyon Formation

Erosion of the Salmon River basin is suspected during the onset of wet climates during the late Miocene. A change to drier conditions during the Pliocene probably caused alluvial erosion to give way to deposition--Pliocene-age gravels may yet be found in the upper elevations of the canyon (Alt and Hyndman 1989:160). As climates became wetter again after ca. 2.5 ma, alluvial erosion continued again along the course previously cut during the late Miocene. Since the beginning of the Pleistocene, alluvial downcutting progressed with vigor. Thus, the Salmon River Canyon is a relatively young geomorphic feature on the western Idaho landscape.

Soil Development

Studies of soil development in the area near the Lower Salmon River Canyon are driven by agricultural interests (Barker 1982) with no emphasis on the description of paleopedological horizons or the use of paleosols to infer paleoenvironmental conditions. Several soil series are been identified in Idaho

County, grouped under names like Bluesprin, Chicane, Lickskillet, Tannahill and Ulhorn, to name but a few. Idaho County soils typically possess mollic epipedons and often include argillic and calcic horizons at varying depths.

Among these series, soil structure is usually controlled by the parent material, with skeletal and granular structures found in soils developed on alluvial fans, colluvium and alluvial terraces. Soils developed on loesses typically retain massive, granular and subangular blocky structures. Epipedon textures range from sandy, loamy, silty clay loam and clay loam, and are strongly influenced by slope and parent material. Solum thickness ranges from 79 cm (31") to 182 cm (72"), dependent upon the depth of parent material to bedrock, slope angle and drainage characteristics.

Late Quaternary Stratigraphy of the Lower Salmon River Canyon Study Area

Stratigraphic units of the study area are defined on the basis of inclusive lithologic, pedologic, and chronologic qualities and are presented in a format similar to that reported in Hammatt (1976). This presentation is broken up into genetic categories, including alluvial, aeolian, mass movement, and colluvial depostion. Stratigraphic units in each of these categories are presented in a general description that includes information on their distribution, origin, age and pedogenic alteration (where observed). Where reference is given to specific stratigraphic study sections, the reader is provided with photographs and stratigraphic figures. The locations of stratigraphic sections and the surficial distribution of geologic deposits (e.g., Qal1) discussed in this study are shown in Map 1. The distribution of stratigraphic units reported in this study are shown in a longitudinal profile (Figures 5 and 6), projected parallel to the course and elevation of the modern Salmon River.

Mass Movement Diamict

Mass movements events are uncommon in the Lower Salmon River Canyon study area. The few events identified are marked by the distribution of poorly-sorted diamict. Irregular, hummocky landforms comprised of a poorly sorted, loosely compacted diamict of clastic material ranging from boulder to pebble sizes, with fine interstitial sediment, are seen near the mouth of Rock Creek. These diamict deposits

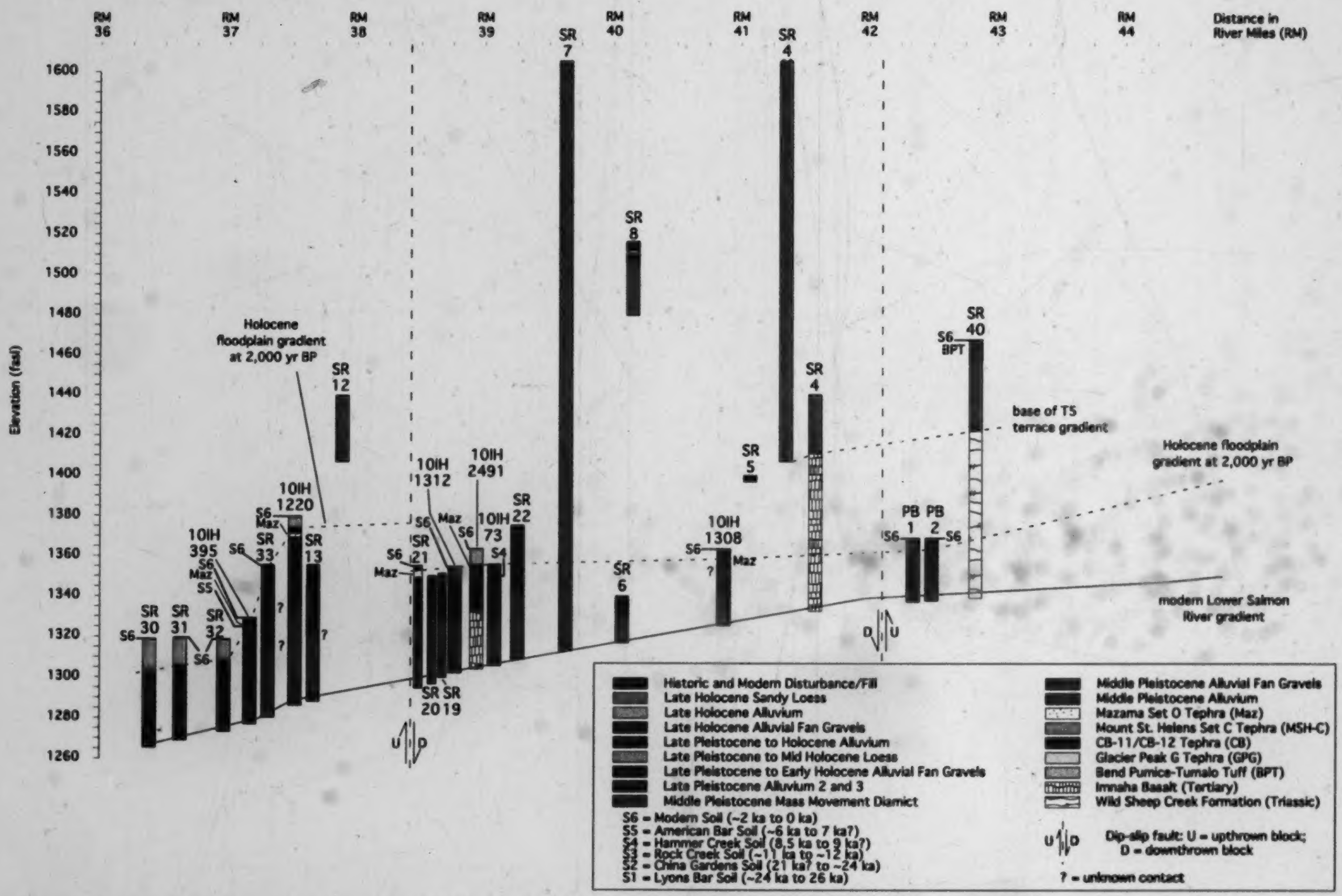
Distance in River Miles (RM)
RM 36
RM 37
RM 38
RM 39
RM 40
RM 41
RM 42
RM 43
RM 44
Elevation (fasl)
1600
1580
1560
1540
1520
1500
1480
1460
1440
1420
1400
1380
1360
1340
1320
1300
1280
1260
SR 30
SR 31
SR 32
10IH 395
SR 33
10IH 1220
SR 13
SR 12
SR 21
SR 2019
10IH 1312
10IH 2491
10IH 73
SR 22
SR 7
SR 8
SR 6
10IH 1308
SR 5
SR 4
PB 1
PB 2
SR 40
S6
S5
S4
Maz
BPT
?
U
D
Holocene floodplain gradient at 2,000 yr BP
base of T5 terrace gradient
modern Lower Salmon River gradient
Historic and Modern Disturbance/Fill
Late Holocene Sandy Loess
Late Holocene Alluvium
Late Holocene Alluvial Fan Gravels
Late Pleistocene to Holocene Alluvium
Late Pleistocene to Mid Holocene Loess
Late Pleistocene to Early Holocene Alluvial Fan Gravels
Late Pleistocene Alluvium 2 and 3
Middle Pleistocene Mass Movement Diamict
S6 = Modern Soil (~2 ka to 0 ka)
S5 = American Bar Soil (~6 ka to 7 ka?)
S4 = Hammer Creek Soil (8.5 ka to 9 ka?)
S3 = Rock Creek Soil (~11 ka to ~12 ka)
S2 = China Gardens Soil (21 ka? to ~24 ka)
S1 = Lyons Bar Soil (~24 ka to 26 ka)
Middle Pleistocene Alluvial Fan Gravels
Middle Pleistocene Alluvium
Mazama Set O Tephra (Maz)
Mount St. Helens Set C Tephra (MSH-C)
CB-11/CB-12 Tephra (CB)
Glacier Peak G Tephra (GPG)
Bend Pumice-Tumalo Tuff (BPT)
Imnaha Basalt (Tertiary)
Wild Sheep Creek Formation (Triassic)
Dip-slip fault: U = upthrown block; D = downthrown block
? = unknown contact

Figure 5. Longitudinal diagram showing position of lithostratigraphic and pedostratigraphic units between RM 36 and RM 45.

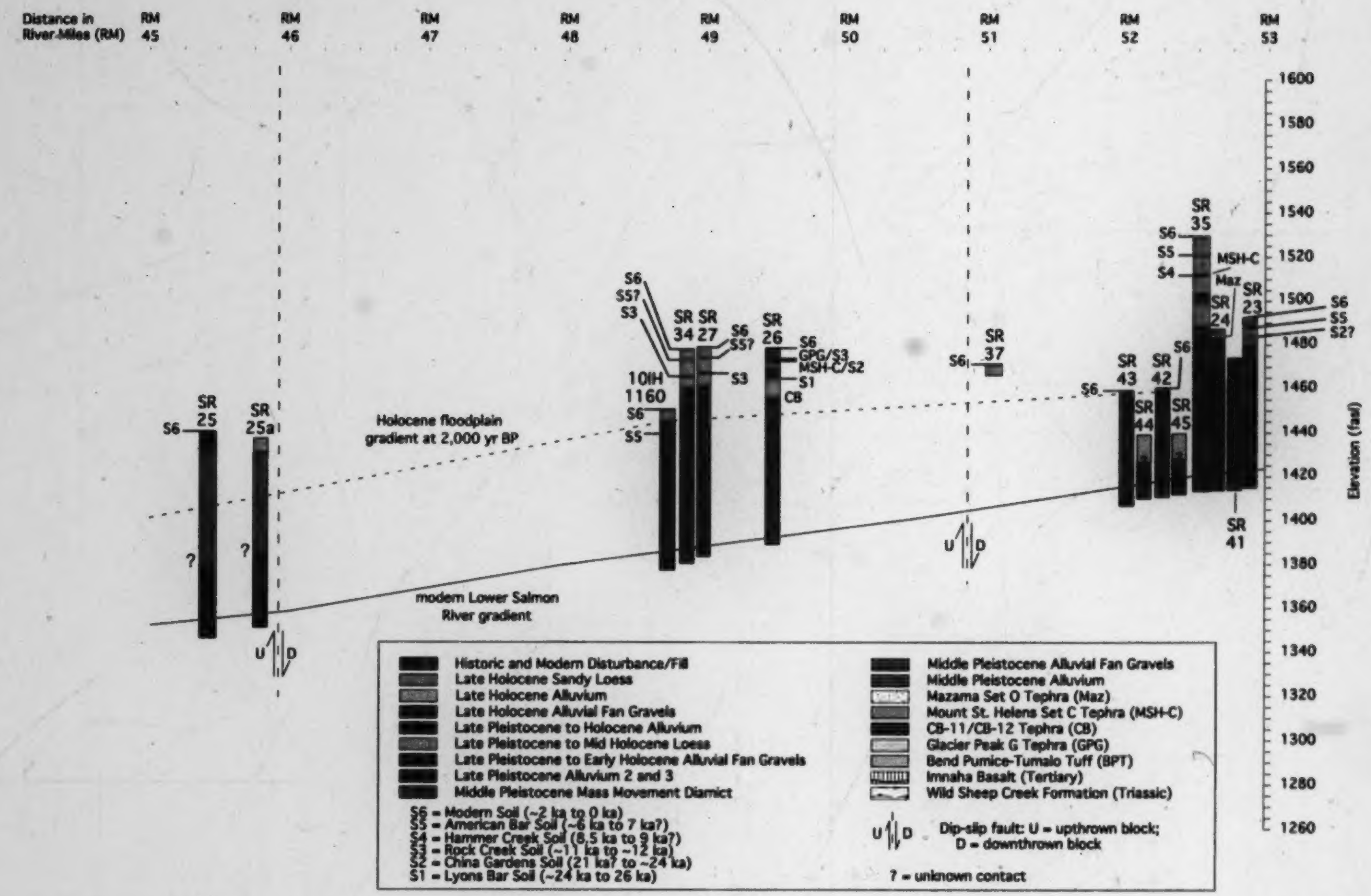
Distance in River-Miles (RM)
RM 45
RM 46
RM 47
RM 48
RM 49
RM 50
RM 51
RM 52
RM 53
Elevation (fasl)
1600
1580
1560
1540
1520
1500
1480
1460
1440
1420
1400
1380
1360
1340
1320
1300
1280
1260
SR 25
S6
?
SR 25a
?
U D
Holocene floodplain gradient at 2,000 yr BP
modern Lower Salmon River gradient
S6
S5?
S3
10IH 1160
S6
S5
SR 34
SR 27
S6
S5?
S3
SR 26
S6
GPG/S3
MSH-C/S2
S1
CB
SR 37
S6
U D
S6
SR 43
SR 44
SR 42
SR 45
S6
SR 35
S6
S5
S4
MSH-C
Maz
SR 24
SR 23
S6
S5
S2?
SR 41
Historic and Modern Disturbance/Fill
Late Holocene Sandy Loess
Late Holocene Alluvium
Late Holocene Alluvial Fan Gravels
Late Pleistocene to Holocene Alluvium
Late Pleistocene to Mid Holocene Loess
Late Pleistocene to Early Holocene Alluvial Fan Gravels
Late Pleistocene Alluvium 2 and 3
Middle Pleistocene Mass Movement Diamict
S6 = Modern Soil (~2 ka to 0 ka)
S5 = American Bar Soil (~6 ka to 7 ka?)
S4 = Hammer Creek Soil (8.5 ka to 9 ka?)
S3 = Rock Creek Soil (~11 ka to ~12 ka)
S2 = China Gardens Soil (21 ka? to ~24 ka)
S1 = Lyons Bar Soil (~24 ka to 26 ka)
Middle Pleistocene Alluvial Fan Gravels
Middle Pleistocene Alluvium
Mazama Set O Tephra (Maz)
Mount St. Helens Set C Tephra (MSH-C)
CB-11/CB-12 Tephra (CB)
Glacier Peak G Tephra (GPG)
Bend Pumice-Tumalo Tuff (BPT)
Imnaha Basalt (Tertiary)
Wild Sheep Creek Formation (Triassic)
U D Dip-slip fault: U = upthrown block; D = downthrown block
? = unknown contact

Figure 6. Longitudinal diagram showing position of lithostratigraphic and pedostratigraphic units between RM45 and RM 53.

blanket bedrock and unconsolidated sediments in this area, and are related to the failure of bedrock units and/or surficial deposits during mass movement events. While only one mass movement diamict unit is formally described here, other much smaller diamict units may be found in areas of the canyon. The first unit is extremely large and easily mapped, and undoubtedly influenced the Late Quaternary geologic history of the Salmon River; units of the second kind are typically quite localized, small in area, are difficult to differentiate from alluvial fan and colluvial gravel deposits, and show little overall influence on the operation of the river.

Devils Garden Slide Diamict (Qls1)

Description

The Devils Garden Slide diamict is characterized by an extremely poorly sorted, clast-supported deposit that includes a wide range of clasts from large boulder to clay-sized particles. The surficial morphology of the diamict is hummocky and retains an overall irregularlity not typically seen in other landforms in the study area. When observed in stratigraphic profile, the clastic component of Qls1 is often angular to subangular with a clast-supported anisotropic fabric (Figures 7-15). Large, relatively unweathered boulders often rest on the irregular surface of the Devils Garden Slide Diamict, differentiating it from alluvial fan or alluvial gravel units.

Distribution

The Devils Garden Slide Diamict is located in the bottom of the canyon between RM 37 and RM 40. Stratigraphic exposures of this unit are almost entirely seen on the northern side of the river in this area. Deposits of the Qm1 diamict can be traced into the Rock Creek canyon, nearly 0.75 miles north of its confluence with the Salmon River. Another extensive deposit of Qm1 diamict is also found overlying much of Bug Slope, to a point just below RM 38. In the lower portion of the study area, Qm1 diamict is found up to 100 m (330') in elevation above the modern Salmon River.

Origin

The origin of the Qm1 diamict can be traced to a large, vertically-displaced bedrock block contained in sections 36 and 31 on the Moughmer Point 7.5' quadrangle map. Devils Garden is located at the top of the slide block in section 36 and is named for its hummocky terrain and widespread distribution of boulders.

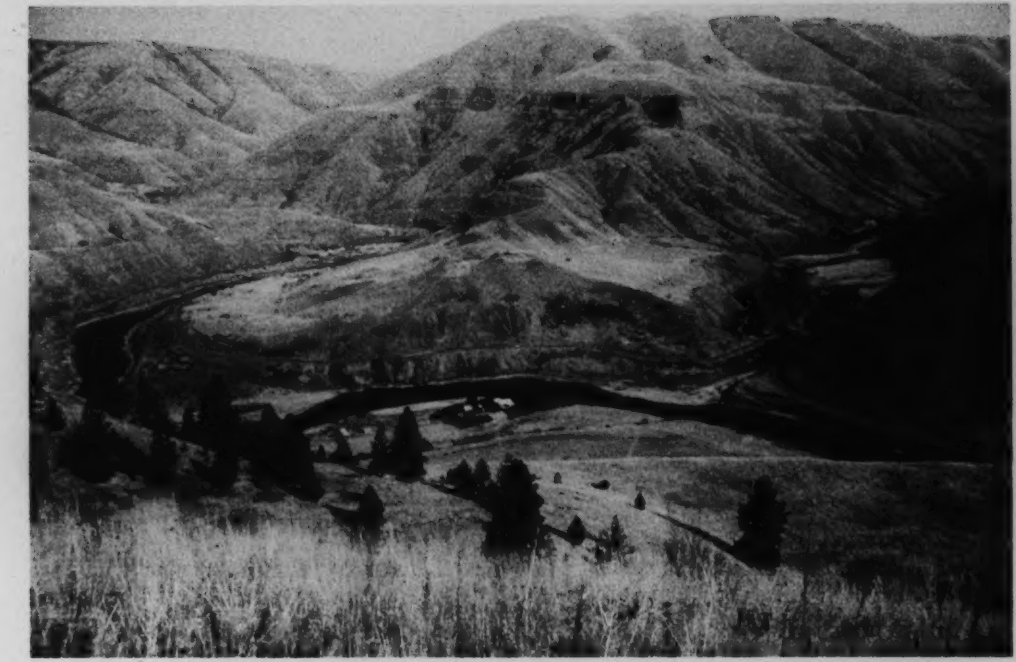

Figure 7. Overview of lower portion of Lower Salmon River Canyon study area, looking north towards mouth of Rock Creek. View is from top of Devils Garden Slide block.

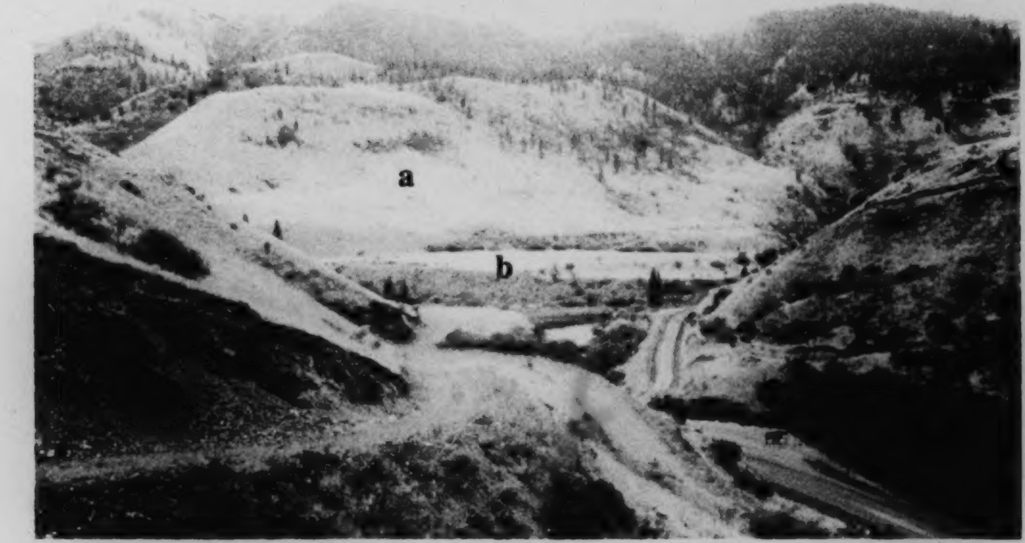

Figure 8. View from surface of Devils Garden Slide diamict deposit in lower reaches of Rock Creek Canyon, looking south towards Devils Garden Slide block (a) and Cooper's Bar (b). Note amount of displacement between darker canyon wall and lighter grass-covered slide block.

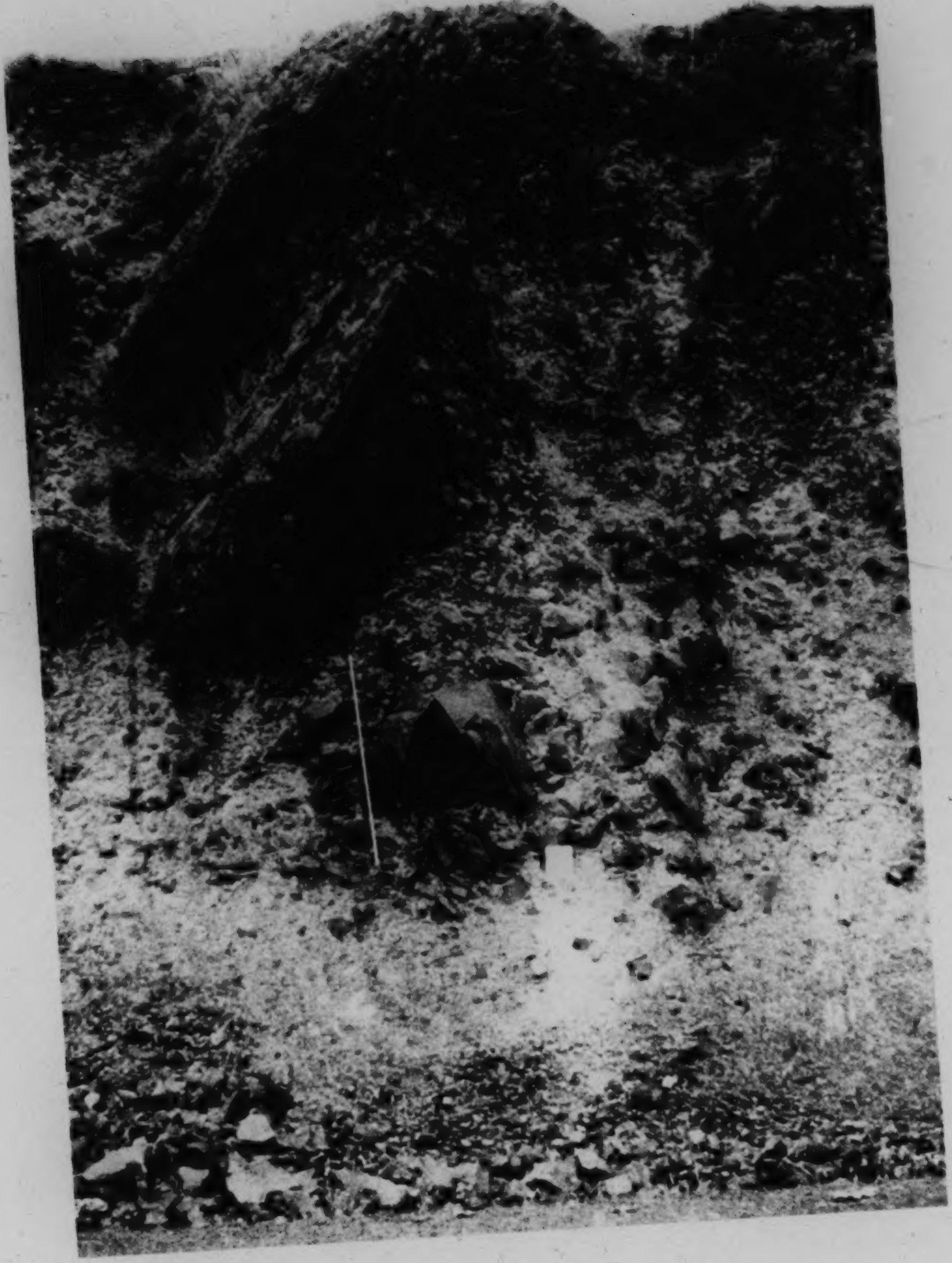

Figure 9. Photograph of poorly sorted Devils Garden Slide (Qls1) diamict seen in the SR-7 section.
Measuring stick is 2.0 m long.

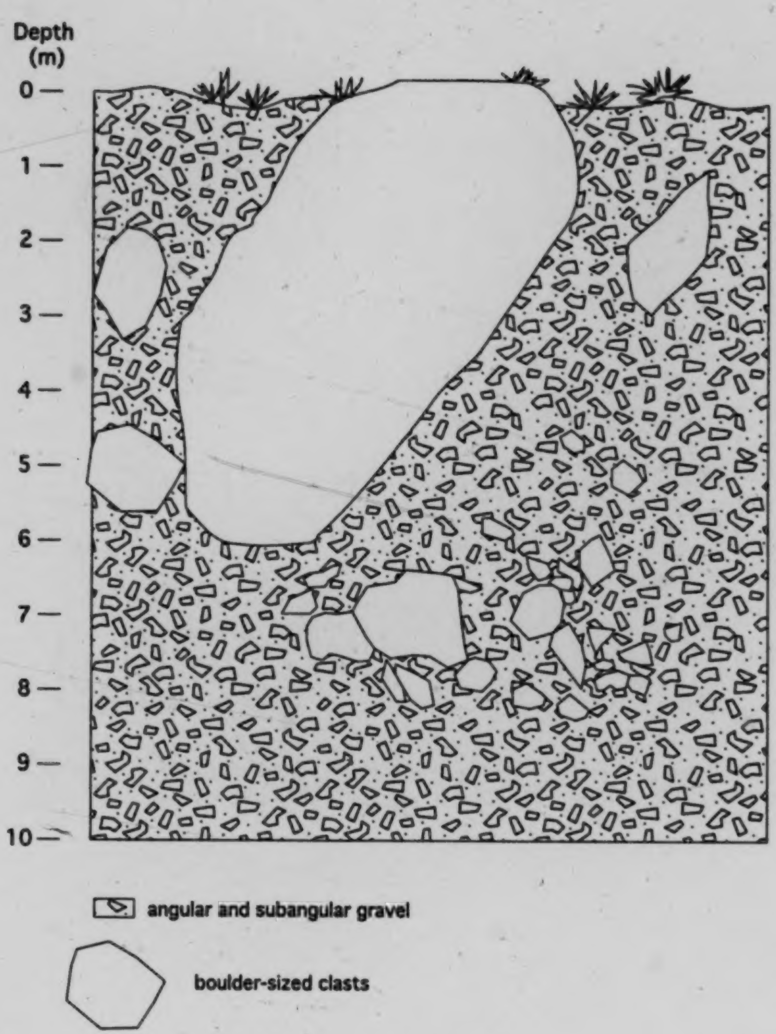
Depth
(m)
0
1
2
3
4
5
6
7
8
9
10
angular and subangular gravel
boulder-sized clasts

Figure 10. Stratigraphy of of SR-7.

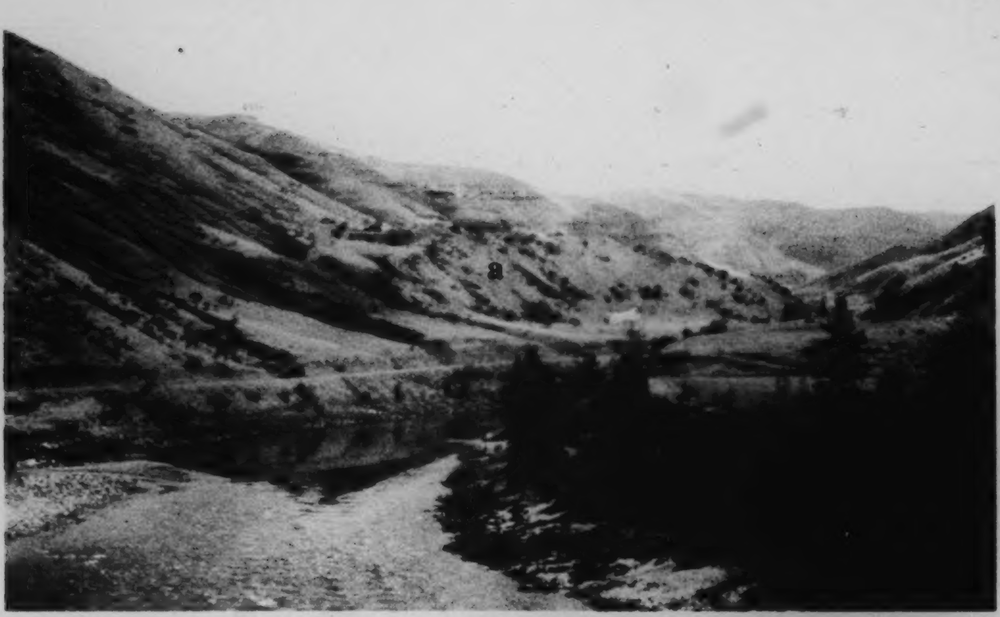

Figure 11. Overview of large Devils Garden Slide diamict (Qls1) deposit (a) near RM 35, overlapping base of canyon slope. Section SR-7 is located at lower edge of deposit along road.

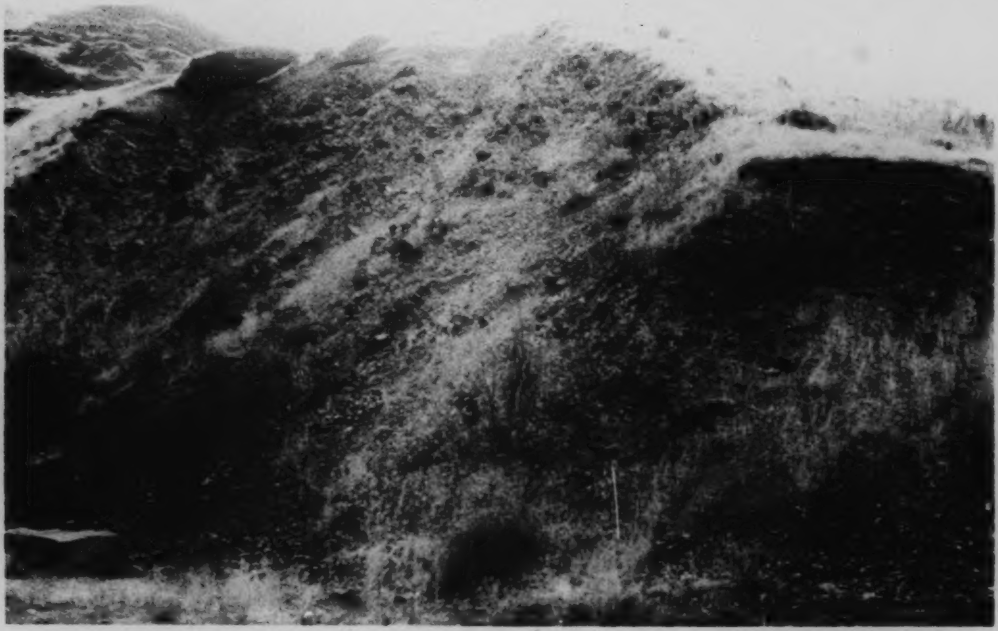

Figure 12. Overview of SR-16 section with exposure of Devils Garden Slide diamict (Qls1). Note poorly sorted matrix, including large boulders on surface. Measuring stick is 2.0 m long

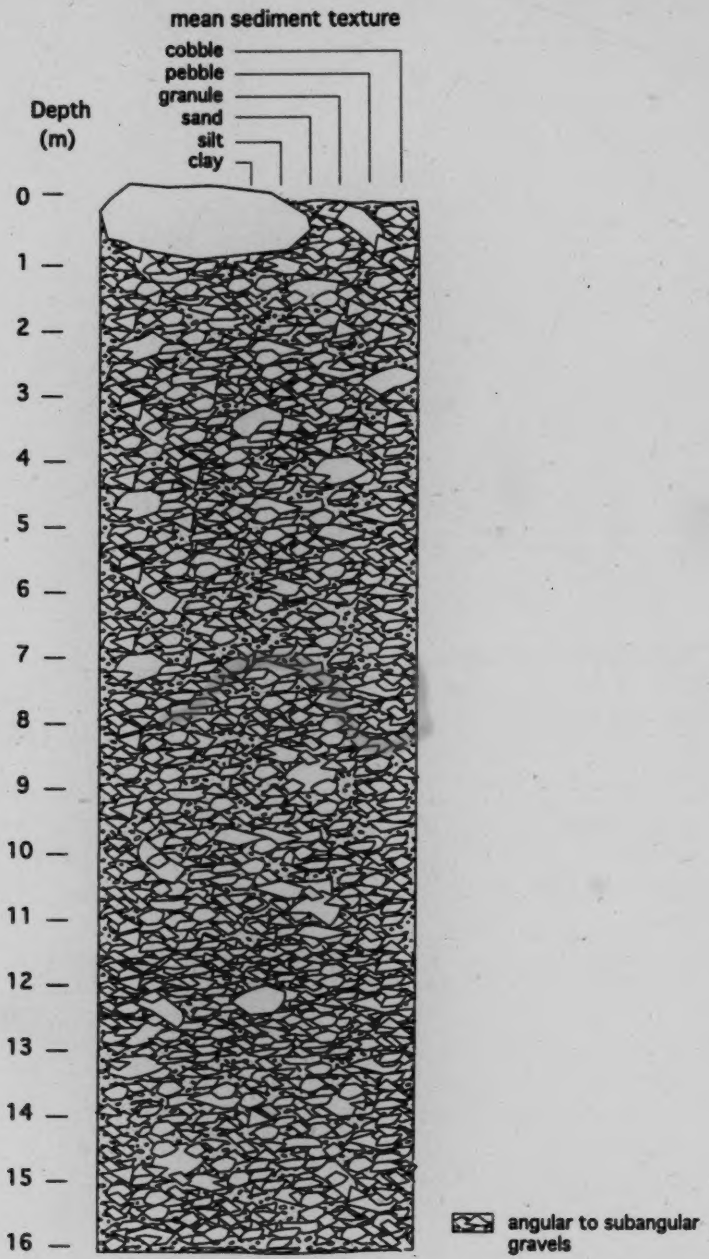
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
angular to subangular gravels

Figure 13. Stratigraphic profile of SR-16. Mean sediment texture refers to the dominant particle size of a given deposit, which is graphically expressed by the length of the depositional unit to the right. In this case, the angular to subangular gravel deposits of SR-16 are dominated bygreater than cobble-sized clasts (clastic size categories follow Wentworth 1922).

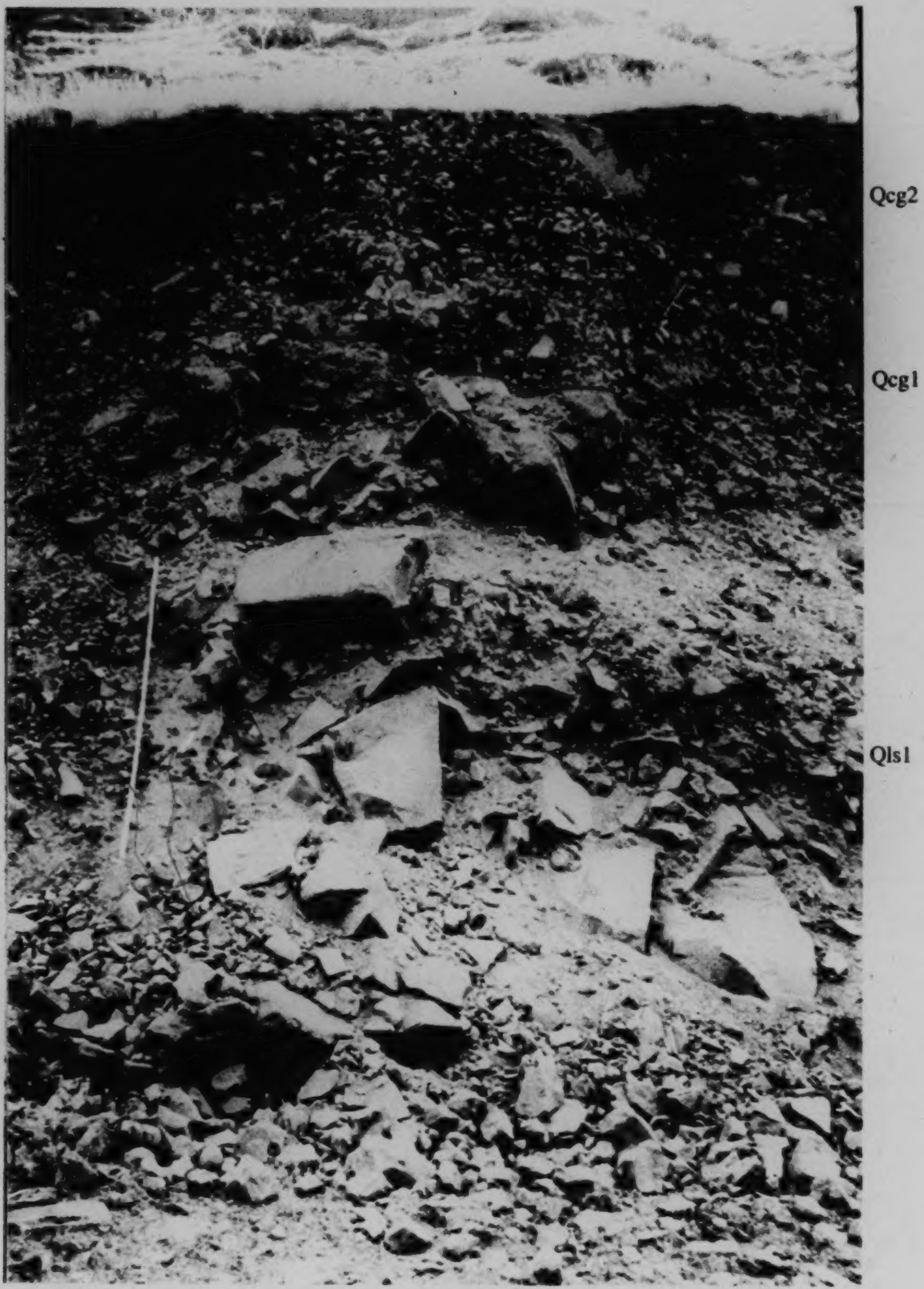

Figure 14. Photograph of SR-15 section, showing Devils Garden Slide diamict (Qls1) at base of profile, overlain by Older Colluvial Gravels (Qcg1) and Holocene Colluvial Gravels (Qcg2). Measuring stick is 2.0 m long.

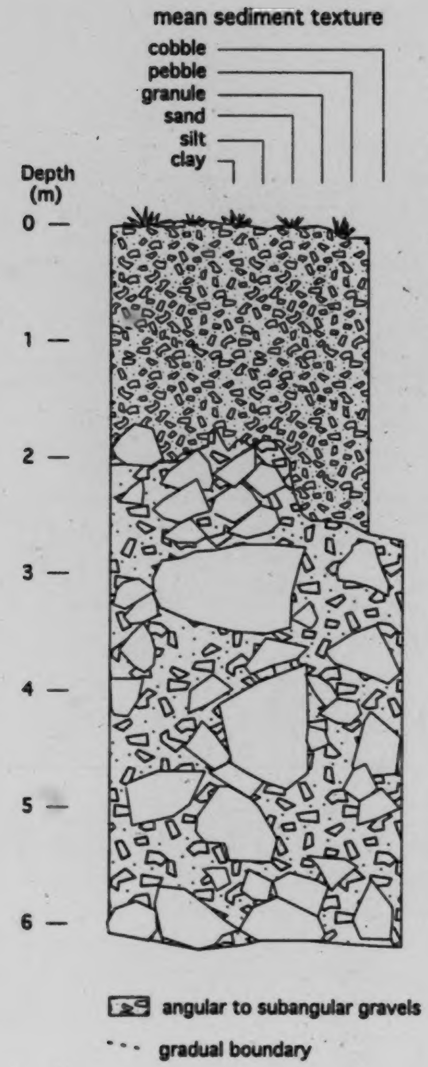
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
6
angular to subangular gravels
gradual boundary

Figure 15. Stratigraphy of SR-15.

A vertical bedrock escarpment forms the southern edge of the Salmon River canyon and Devils Garden, having been created as the Devils Garden slide block moved downward into the canyon. Debris created during the landslide was distributed predominantly to the northern side of the Salmon River Canyon, undoubtedly impounding the flow of the Salmon River for some time.

Age (>350 to 400 ka)

The age of the Devils Garden Slide is indirectly established from alluvial deposits (Qal1) that probably accumulated behind the canyon fill created after the slide event. On this basis, the Qm1 diamict predates the deposition of the Bend Pumice (350 to 400 ka) directly overlying the Early Pleistocene Alluvium.

Alluvial Deposits in Terrace Landforms

Nineteen point bars are seen in the Lower Salmon River Canyon study area between the mouth of Hammer Creek and the end of American Bar along the modern channel. Positioned at the inside of meander bends of the river, these landforms are generally elongate and exhibit nearly-flat to gently sloping surfaces that trend toward the river. Depositional units in point bars commonly form a generalized stratigraphic sequence of basal rounded to subrounded alluvial gravels that fine upwards into sands and silts; these alluvial units are typically covered by aeolian sands and silts. Older point bar deposits are found at positions above the modern floodplain, contained in five terraces spanning 400 ka. These features are unequally distributed in the study area, with a greater number of larger point bars found in the lower portion below Pine Bar rapids (RM 42.5).

The T0 Terrace

The T0 terrace was subjected to occasional flooding by the Salmon River during the last two millennia. During high flood events, which occur at centennial or multi-decadal scales the upper limits of the T0 terrace are submerged (e.g., during the 1974 flood, which exceeded 3681.6 cms (130,000 cfs) at the White Bird gauging station (United States Geological Survey 2001)). In years with smaller spring runoff events, flooding occurs along the lower limits of the T0 terrace, where it reworks rounded to subrounded gravels and replenishes quartz-rich sand beaches. In many places along the Lower Salmon River this terrace was partially or entirely destroyed by historic hydraulic placer mining activity. Examples of the T0 terrace are seen at the Hammer Creek Recreation Site campground (RM 52.5), Lone Pine Bar (RM 41.4), and in the area of Pine Bar (RM 42-42.5). This terrace occurs up to ca. six m (20') above the channel of the Salmon River. The formation of the T0 terrace is dated after ca. 2,000 yr BP.

The T1 Terrace

The T1 terrace often occurs adjacent to the T0 terrace and was also subjected to hydraulic placer mining in many areas. Above McCulley Creek, the terrace is seen up to 18 m (60') above the modern Salmon River, while in the area of Bug Slope, the terrace is found up to ca. 24 m (80') above the river. Narrower in width than the T0 terrace in most places, the T1 terrace contains a similar stratigraphic sequence: a fining-upwards sequence of alluvial gravels, sands and loamy sands are occasionally covered by an aeolian sandy loess in the upper portion of the study area. In the lower portion of the study area, this terrace takes the form of broad floodplain segments (e.g., Bug Slope, upper portion of Pine Bar), which contain sediments with textures dominated by silt and clay, over alluvial gravels. The lower portion also lacks a blanketing cover of aeolian sediments. Alluvial deposition of this terrace in the upper portion of the study area began before 8,760 yr BP and ended soon after 2,340 yr BP and between ca. 12,000 and ca. 1,900 yr BP in the lower portion.

The T2 Terrace

The T2 terrace is most prominent in the upper portion of the study area, upstream of McCulley Creek. This terrace occurs up to ca. 58 m (190) above the Salmon River channel. This terrace contains thicker deposits than other terraces, comprised of alluvial gravels overlain by alluvial sand and loamy sand. Fine-textured aeolian loess units and alluvial fan gravels cap the alluvial deposits of the T2 terrace in some areas. Two prominent paleosols are contained in this terrace, including the Lyons Bar Soil and the China Gardens Soil. Alluvial deposition on the T2 terrace apparently began before 60-70 ka and ceased before ca. 12,000 yr BP on the basis of inclusive tephras and radiocarbon dates.

The T3 Terrace

The T3 terrace is represented at Cooper's Bar (RM 39). This terrace is comprised of thick boulder- and cobble-sized alluvial gravels reworked from the Devils Garden Slide diamict present in part of the lower portion of the study area. This terrace is capped by a thin (<1 m) deposit of aeolian sands and silts, and is found up to 30 m (100') above the channel of the Salmon River. The T3 terrace predates the formation of the T2 terrace on the basis of its elevation, and is thus older than ca. 70 ka, but younger than the T5 terrace, which contains a tephra layer erupted at 400 ka.

The T4 Terrace

The T4 terrace lies immediately adjacent to the T3 terrace at Cooper's Bar. This terrace is composed of reworked Devils Garden Slide diamict and contains boulder- to cobble-sized gravels, which are blanketed by a thin deposit of aeolian sand and silt. The surface of this terrace lies up to 43 m (140') above the modern Salmon River channel. The T4 terrace predates the formation of the T3 terrace, making it older than 70 ka, but postdates the T5 terrace, making it younger than 400 ka.

The T5 Terrace

The T5 terrace is only seen in the lower portion of the study area up to ca. 82 m (ca. 270') above the present channel of the Salmon River. Exposed by placer mining at SR-40 and SR-4, this terrace is comprised of rounded alluvial gravels overlain by beds of silts and sands. In some areas, alluvial fan gravels and fine sediments cap this terrace. A minimum age for the T5 terrace is provided by the presence of the Bend Pumice, which dates between ca. 350 to 400 ka (Sarna-Wojcicki, written communication 1999). This tephra is found at SR-40 in an alluvial fan deposit that overlies a paleosol developed in the alluvium of the T5 terrace.

Alluvial deposits of varying textures and lithologies are found in several places in the study area, and are most commonly seen in terraces (with alluvial fans being the sole exception). Five alluvial deposits are defined here, ordered by decreasing age as determined by radiocarbon dates and associated volcanic tephras.

Middle Pleistocene Alluvium (Qal1)

Description

Thick deposits of rounded to subrounded cobble and boulder gravels form discontinous terraces in the highest alluvial deposit found in the study area. Gravel lithologies include Columbia River Basalts, Seven Devils Group metamorphics, nonbasaltic igneous rocks and older metamorphic rocks (Kuhns 1980; Webster et al. 1982); this assemblage of clastic lithologies will be referred to as *mixed lithology gravels* in following sections. Although Qal1 gravels are almost always clast-supported, fine silt is often seen as interstitial sediment. Where Qal1 sediments are found near tributary canyons or are capped by/interfinger with alluvial fan deposits, gravels can be cemented by secondary carbonate deposition and may show advanced weathering; these differences are thought to be related to diagenetic effects during interaction with groundwater and alluvial runoff.

Distribution

The deposit is seen upriver of RM 39.5 up to an elevation of ca. 488 masl (1600' asl) where it forms the T5 terrace. Exposures of Qal1 are found at SR-8, SR-4, SR-40 (Figures 16 and 17), and gravels can be traced out as float on the canyon flanks from RM 40.5 and RM 42 between 431 to 488 masl (1400' to 1600' asl). Large rounded to subrounded cobbles and boulders are also seen to form the base of the T5 unit between RM 51 and RM 52.

Origin

Deposition of the Qal1 unit apparently followed the Devils Garden Slide event. After Qm1 diamict filled the canyon in the area of Rock Creek to an elevation of 488 masl (1600' asl), the Lower Salmon River likely began aggrading its channel, producing a thick gravel deposit.

Age (>350-450 ka)

The Middle Pleistocene Alluvium underlies the Bend Pumice at SR-40. This provides a minimum age of >350 to 400 ka (Sarna-Wojcicki, written communication 1999) for the timing of deposition of the Late Pleistocene Alluvium 1.

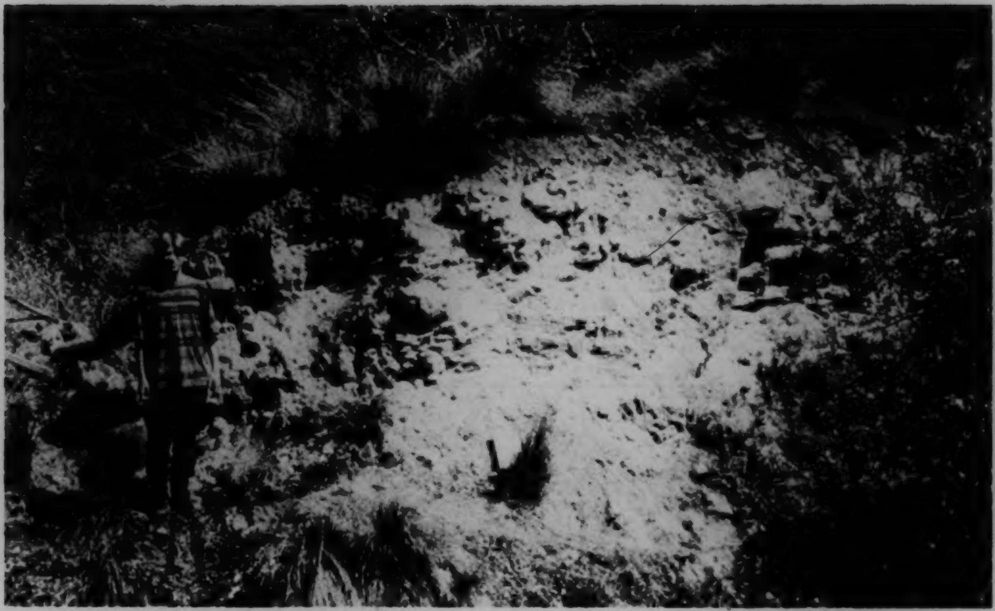

Figure 16. Overview of SR-40 stratigraphic section. Person standing is about 180 cm tall.

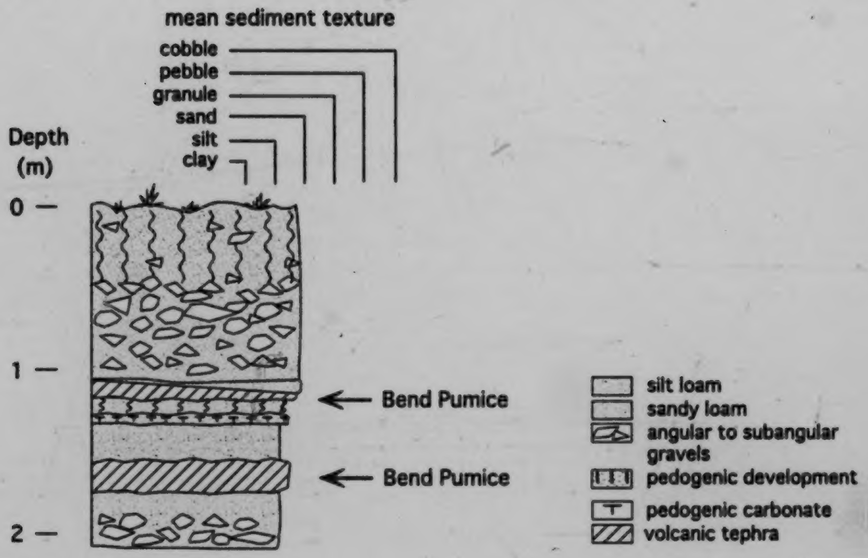
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0 —
1 —
2 —
Bend Pumice
Bend Pumice
silt loam
sandy loam
angular to subangular gravels
pedogenic development
pedogenic carbonate
volcanic tephra

Figure 17. Stratigraphy of SR-40.

Late Pleistocene Alluvium 1 (Qal2)

Description

Horizontally bedded sandy and loamy sand deposits overlie rounded mixed lithology and basaltic gravels in the upper reach of the study area, comprising higher terraces, and in few exposures downriver. Bedding may occur in horizontal units with small wedge-like features, which are suspected as being periglacial features (perhaps desiccation cracks). An example of this deposit with wedge features is seen at SR-26-3 (Figure 18).

Distribution

The Qal2 unit is seen in placer mining exposures in the upper portion of the study area, up to ca. 20 m (ca. 66') above the channel of the Salmon River. Localities such as SR-19, SR-20, and SR-26-3, provide exposures of this unit (Figures 19-23), although more of the deposit may be buried in the study area beneath younger sediments.

Origin

The origin of the thick mixed lithology and basalt gravel component of the Qal2 unit is probably related to two distinct processes. First, after the Devils Garden Slide dam was breached by the Salmon River, the Qal1 canyon fill would be incised as the river sought to establish a new channel gradient. Second, glacial activity in the upper reaches of the Salmon River basin would be expected to introduce new, and perhaps abundant, clastic material into the alluvial system. Combined, these two factors likely slowed the process of reworking the older canyon fill. Reworked canyon fill can be seen in exposures along the edge of Cooper's Bar (e.g., SR-19 and SR-20) and in the Salmon River road cut between RM 39.25 and RM 37.5, as alluvial processes rounded and redeposited Devils Garden Slide diamict clasts, producing a Qal2 unit dominated by basalt.

The finer fraction of the Qal2 is found in horizontally-bedded, low-angle deposits adjacent to the river. These sands appear to originate as overbank alluvial sediments, perhaps accumulating seasonally. Qal2 sediments are dominated by plagioclase and quartz grains, and include a greater silt content than modern alluvial sands.

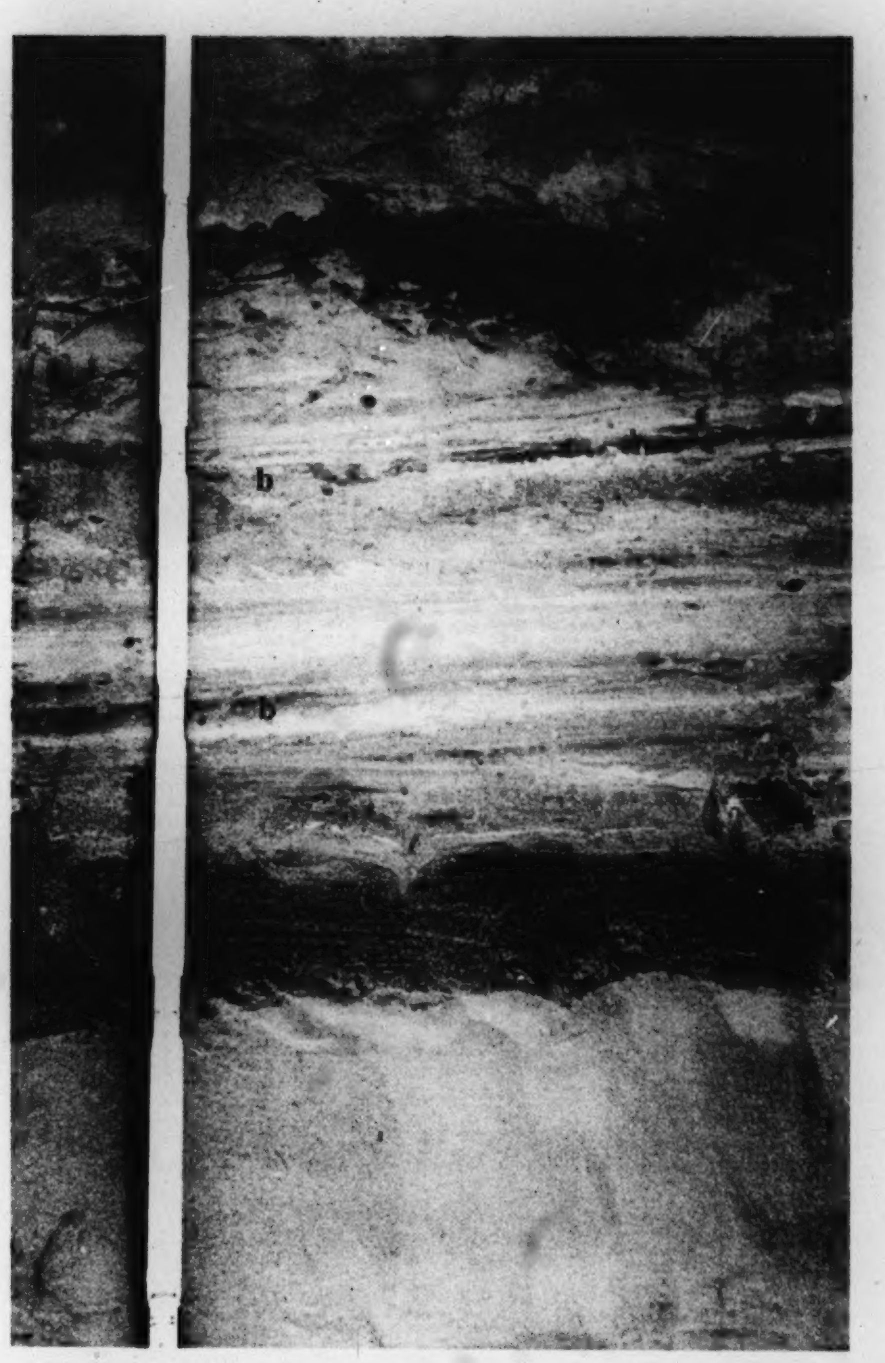

Figure 18. Closeup of SR-26-3 profile showing potential periglacial sand wedge feature (a). CB11/CB12 tephra layers here (b) have a distinctive purple hue in color.

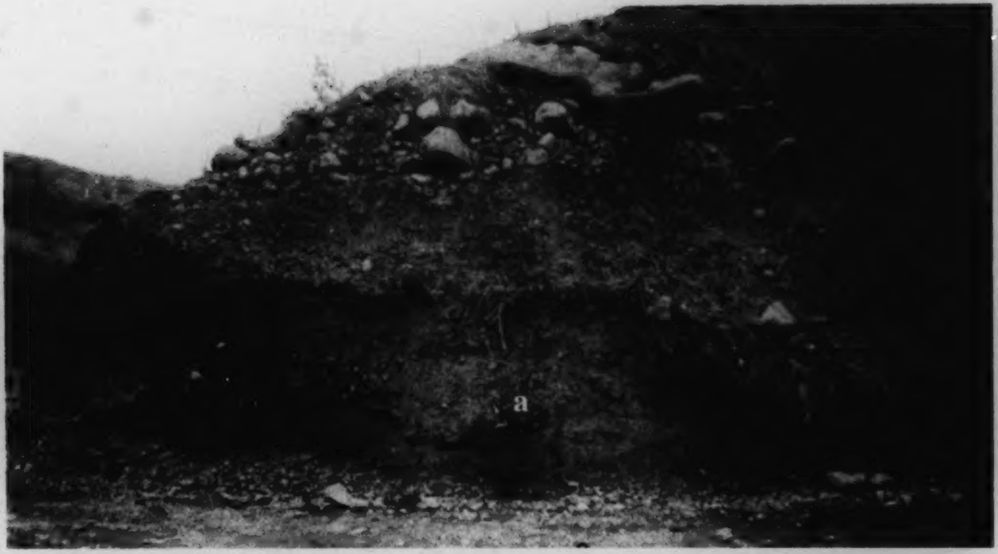

Figure 19. Exposure of Late Pleistocene Alluvium 1 (Qal2) gravels at SR-19. Hammer (a) provided for scale.

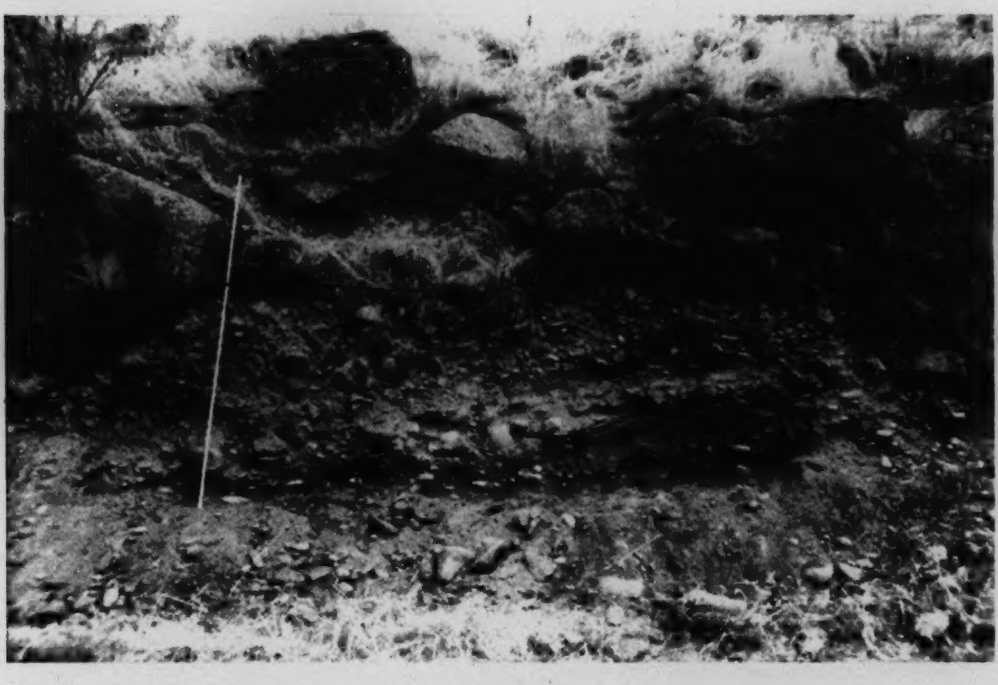

Figure 20. Photograph of SR-20 section, showing large boulder gravels of the Late Pleistocene Alluvium 1 (Qal2) deposit overlying earlier alluvial deposits. Measuring stick is 2.0 m long.

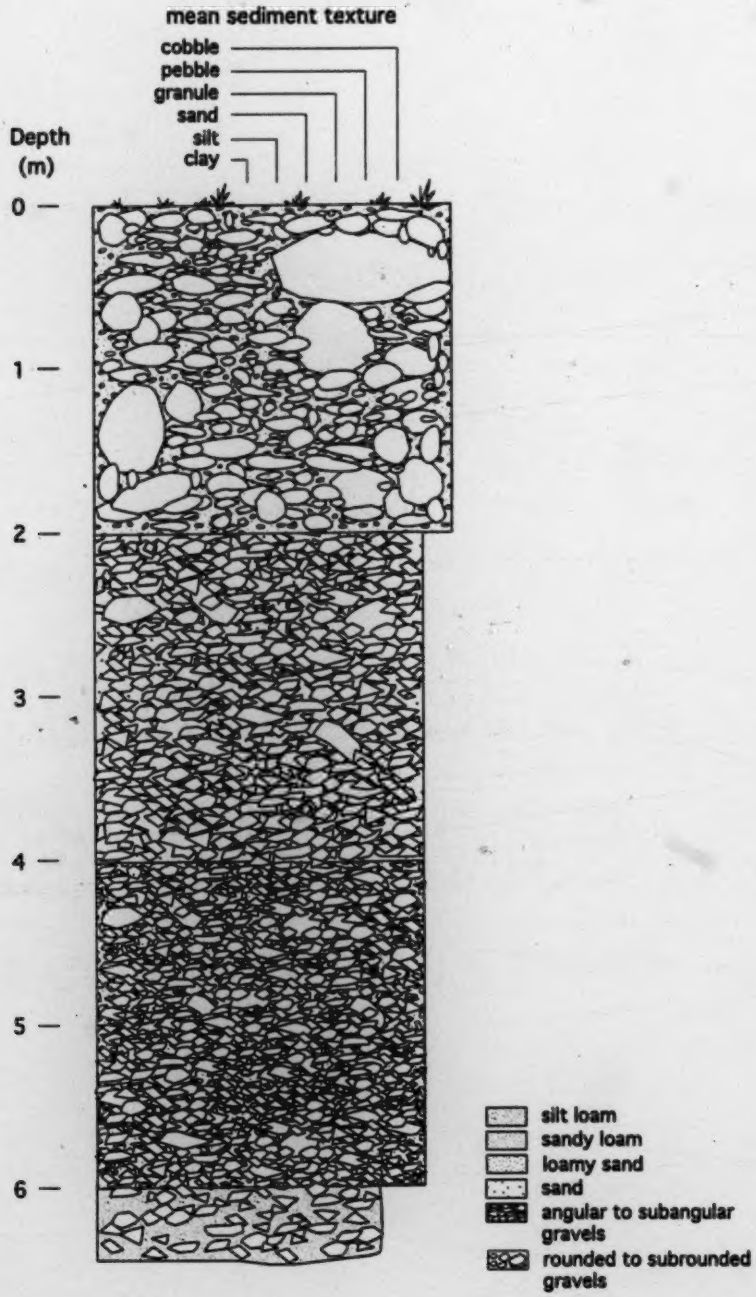
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
4
5
6
silt loam
sandy loam
loamy sand
sand
angular to subangular gravels
rounded to subrounded gravels

Figure 21. Stratigraphy of SR-19

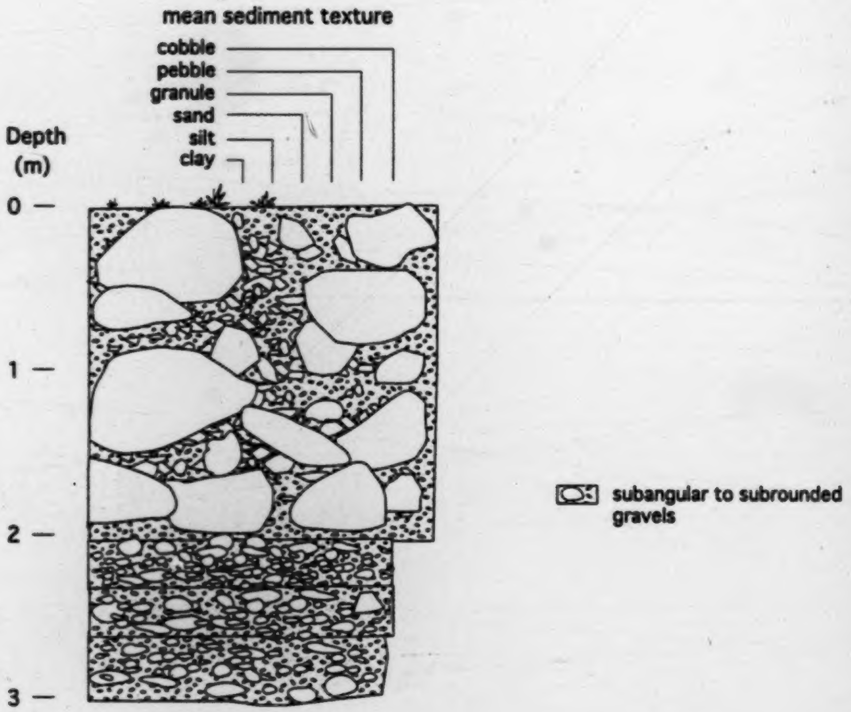
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
subangular to subrounded gravels

Figure 22. Stratigraphy of SR-20.

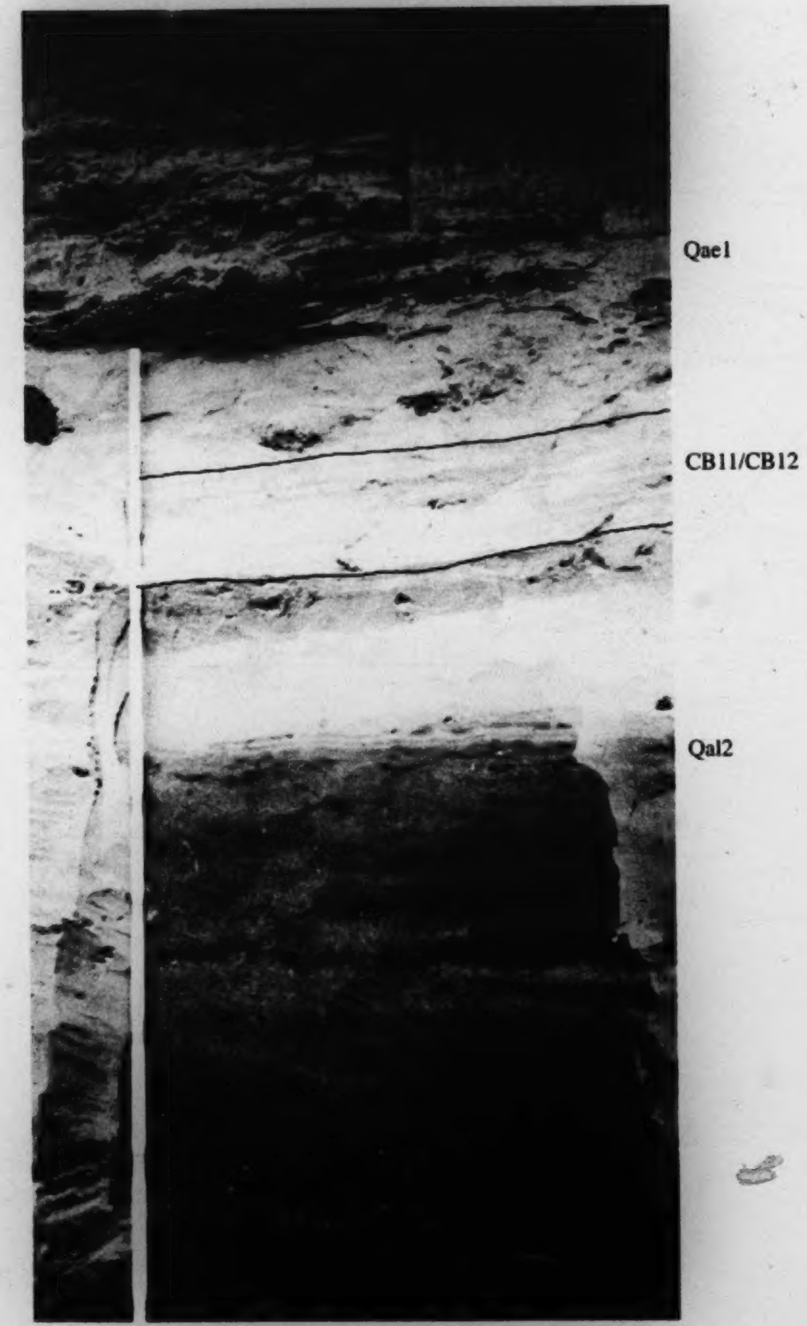

Figure 23. Photograph of SR-26-3 profile showing Late Pleistocene Alluvium 1 (Qal2) overlain by Light colored tephra layers identified as CB11/CB12, originating from a central Oregon source between 60-70 ka. Late Pleistocene Loess 1 (Qae1) with Lyons Bar Soil development is seen at top of profile. An AMS date on humates from this paleosol returned a date of 25,270 ±530 yr BP.

Age (>60-70 ka to <350-400 ka)

An upper limiting age for the Late Pleistocene Alluvium 1 unit is provided at SR-26-3 by the presence of the Crater Lake tephra unit CB-11/CB-12, which is dated between ca. 60 to 70 ka (Sarna-Wojcicki, written communication 1999), immediately over Qal2 sands. The lower limiting age of the Qal2 unit is marked by the end of Qal1 gravel deposition, which predate 350 to 400 ka.

Late Pleistocene Alluvium 2 (Qal3)

Description

The Late Pleistocene Alluvium 2 is comprised of well rounded to subrounded cobble and pebble gravels of either mixed or basaltic lithology, overlain by medium to fine quartzitic sands with occasional micas. The unit lacks internal bedding structures and is typically between 5 and 2 m in thickness.

Distribution

This deposit is seen in many areas of the study area, providing the basal unconsolidated deposits of the T1 and T0 terrace. Exposures of the Late Pleistocene Alluvium 2 are seen at SR-21, SR-23, 10IH395, 10IH73, SR-41, SR-43, up to ca. 18 m (60') above the modern Salmon River channel (Figures 24-36). Alluvial downcutting during the late Holocene probably incised into the surface of the Qal3. In many areas, extensive gravels underlie late Holocene floodplain deposits; these gravels are thought to be the lagged remnants of older alluvial canyon fill units (including Qal3).

Origin

The Qal3 unit is interpreted as deposited during seasonal overbank sedimentation under a glacial environment. The sedimentary character of this deposit differs from earlier alluvial units, being dominated by weakly-bedded sandy and loamy sand sediments.

Age (>15,000 to >11,400 yr BP)

An upper limiting age for the Late Pleistocene Alluvium 2 is provided by radiocarbon dates of 11,370 ±40 yr BP (Beta-114949) and 11,410 ±130 yr BP (TO-7349) in overlying units at 10IH73. Soil humates from loess overlying the Qal3 unit at SR-23 point to alluvial deposition before 14,930 ±1,030 yr BP (TO-7818) in the upper portion of the study area. While alluvial deposition at SR-23 ended, giving way

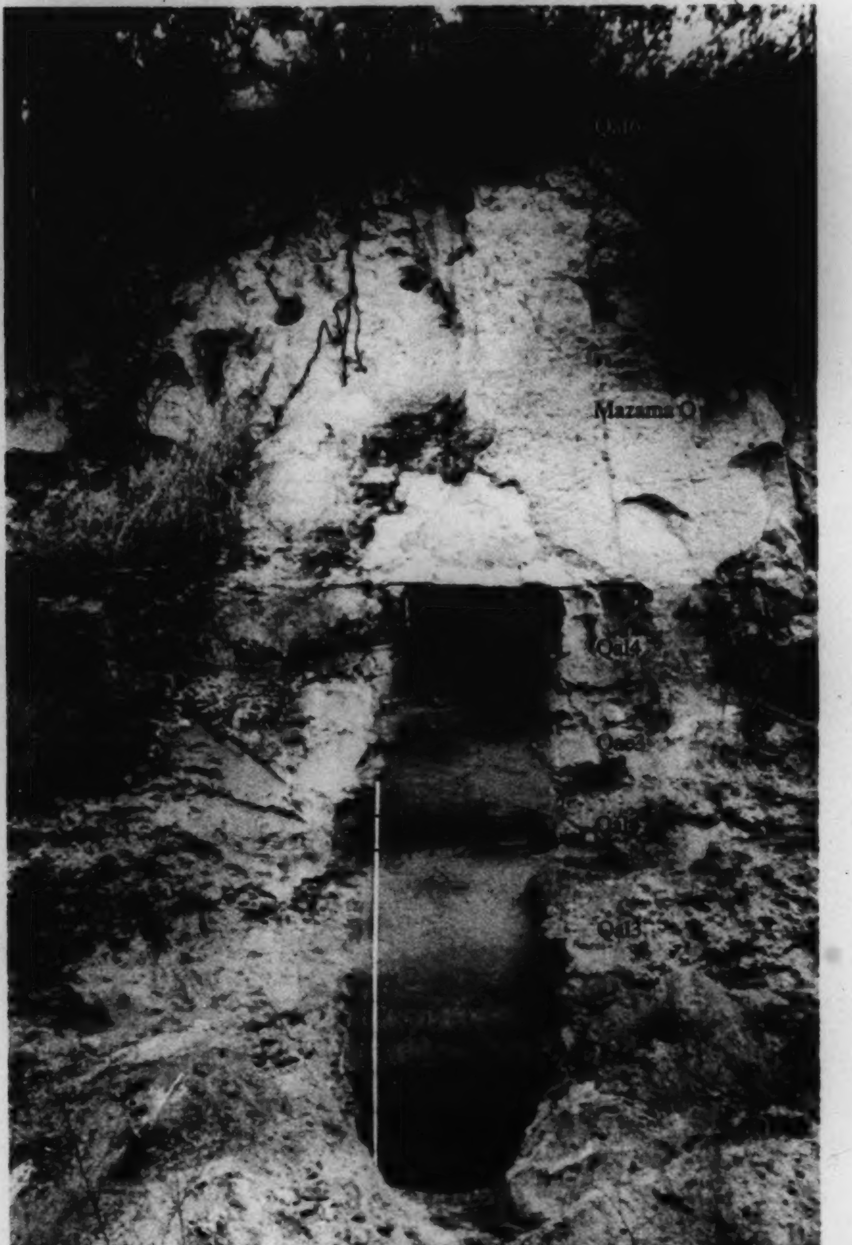

Figure 24. Photograph of SR-21 section. Thick white unit at top of profile is Mazama O tephra. Deer bone found lying on dark Late Pleistocene-Holocene Alluvium (Qal4) layer, located near top of measuring stick, returned an AMS date of 11,320 ±80 yr BP. Qal4 deposit is immediately overlain by Late Pleistocene-Early Holocene Loess (Qae3). Measuring stick is 2.0 m long.

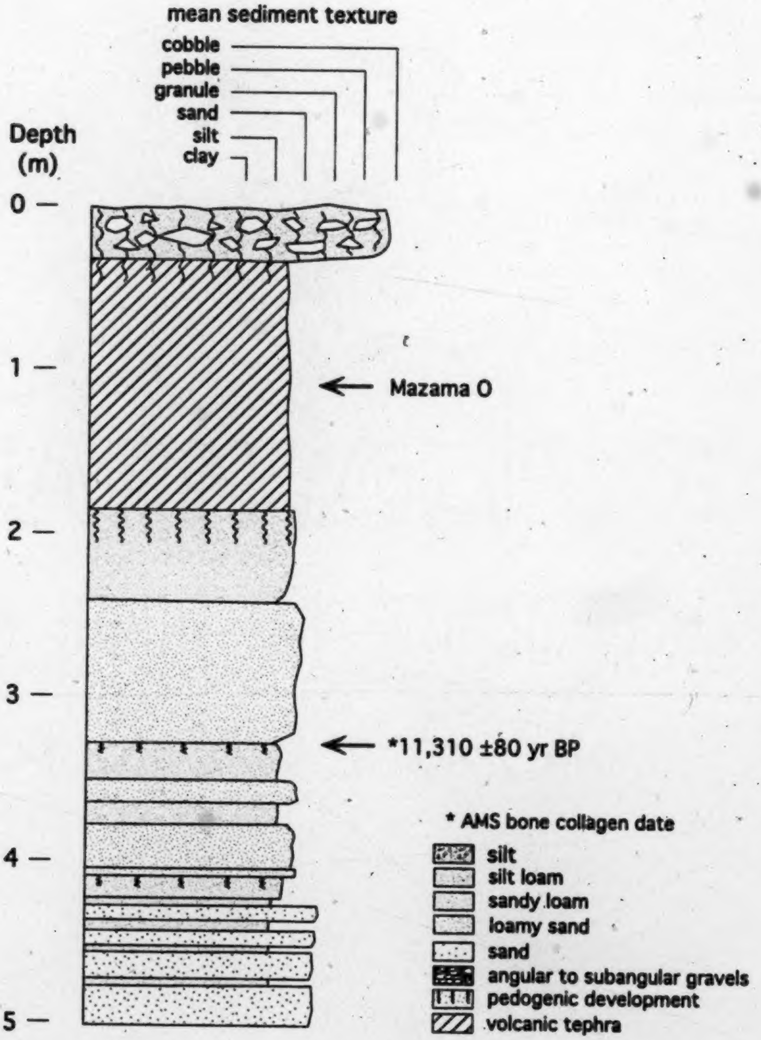
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
Mazama O
*11,310 ±80 yr BP
* AMS bone collagen date
silt
silt loam
sandy loam
loamy sand
sand
angular to subangular gravels
pedogenic development
volcanic tephra

Figure 25. Stratigraphic profile of SR-21.

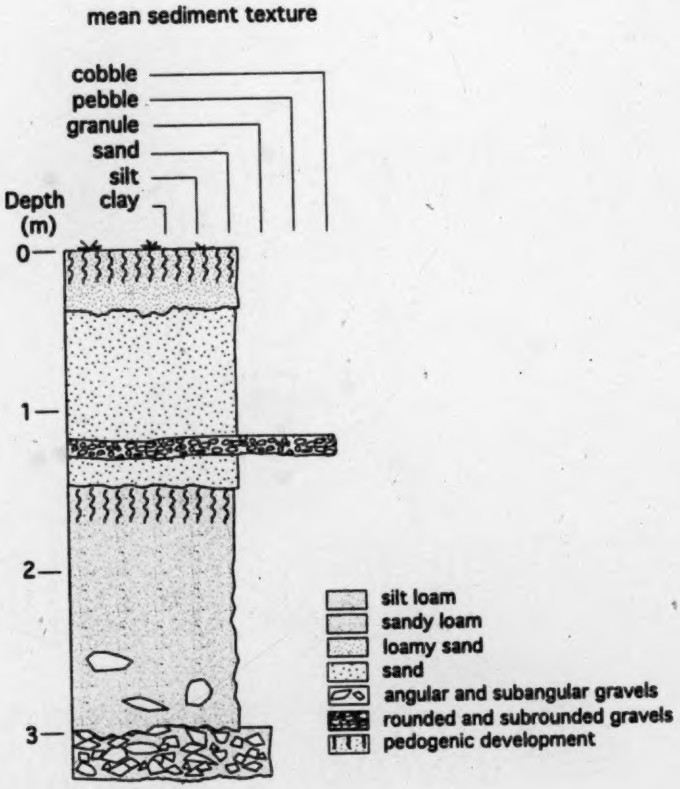
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
silt loam
sandy loam
loamy sand
sand
angular and subangular gravels
rounded and subrounded gravels
pedogenic development

Figure 26. Stratigraphy of SR-33.

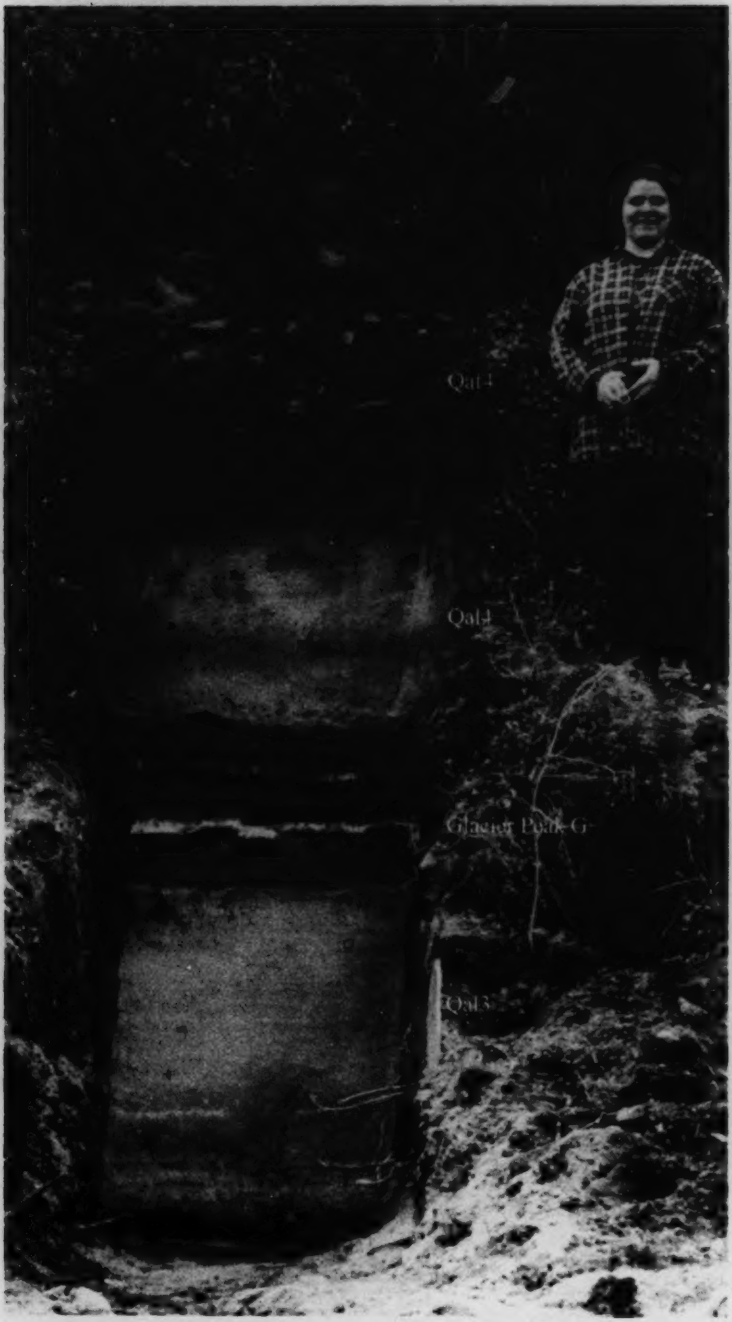
Qal4
Qal4
Glacier Peak G
Qal3

Figure 27. Lower portion of SR-43 section stratigraphy. Person is about 160 cm tall. White layer of tephra identified as Glacier Peak G. Late Pleistocene Alluvium 2 (Qal3) underlies the tephra.

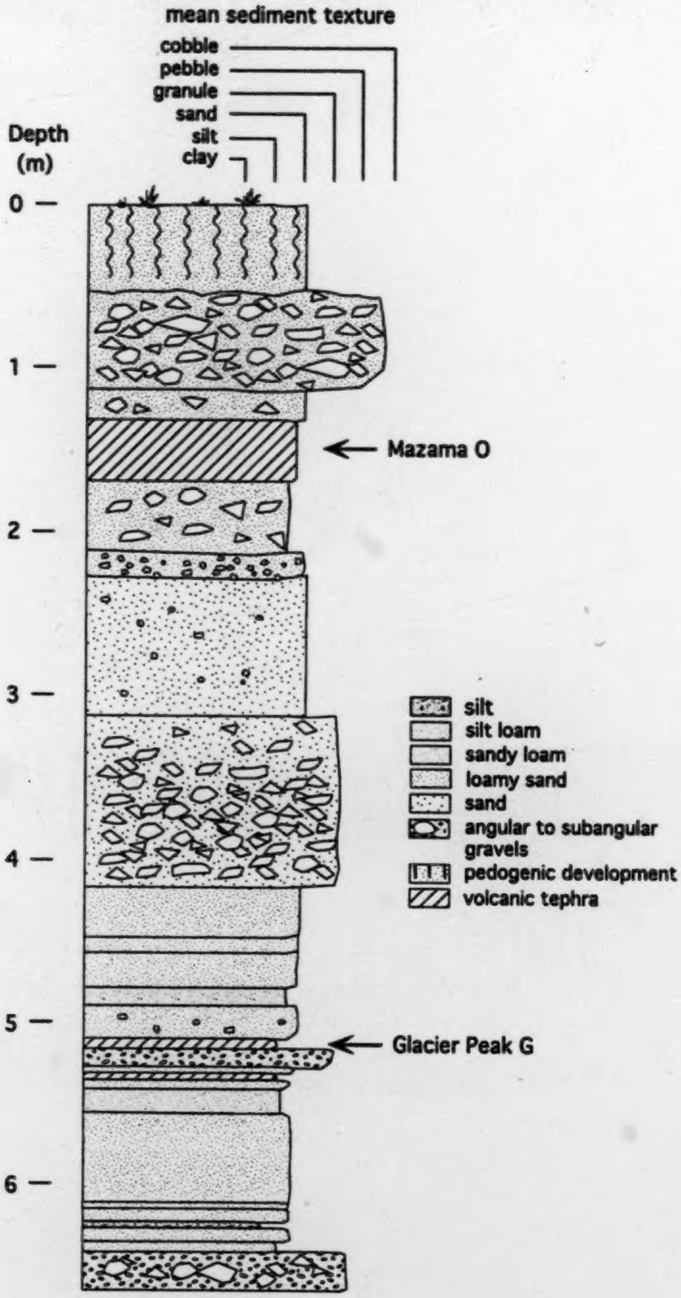
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
4
5
6
Mazama O
Glacier Peak G
silt
silt loam
sandy loam
loamy sand
sand
angular to subangular gravels
pedogenic development
volcanic tephra

Figure 28. Stratigraphy of SR-43.

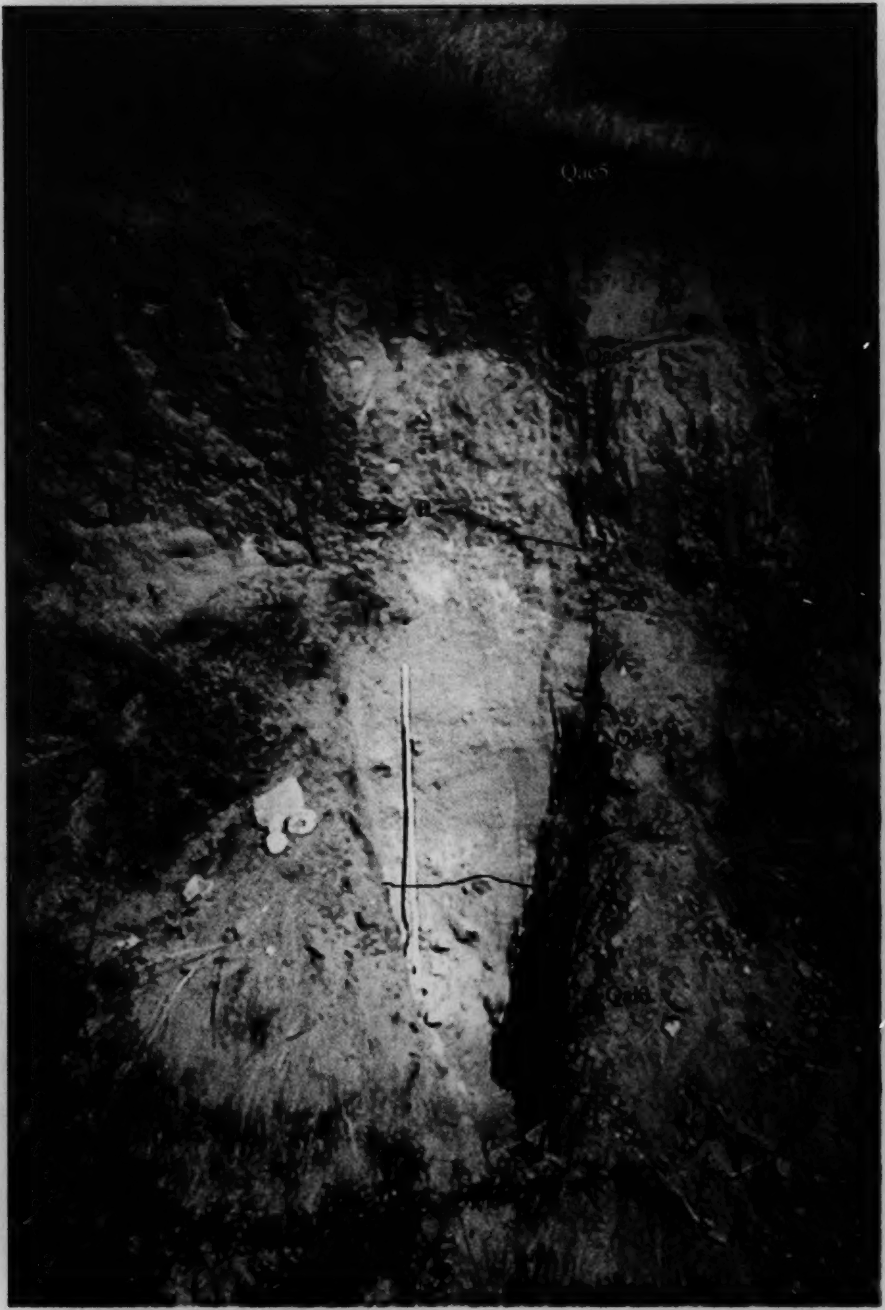

Figure 29. Photograph of the SR-23 section. Late Pleistocene Alluvium 2 (Qal3) is seen at base of profile overlain by Late Pleistocene Loess 2 (Qal2). Middle Holocene Sandy Loess (Qae4) is found above erosional unconformity (a). Section is capped by layer of Late Holocene Sandy Loess (Qae5). Scale is 2.0 m long.

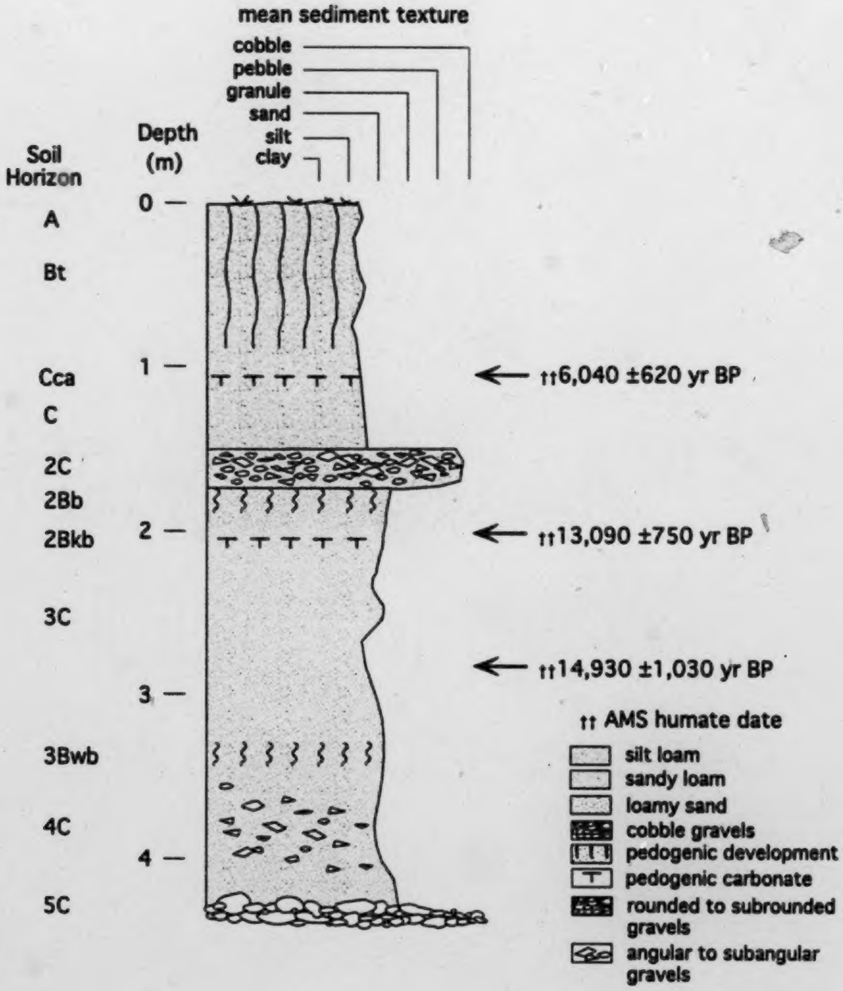
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Soil Horizon
Depth (m)
0
1
2
3
4
A
Bt
Cca
C
2C
2Bb
2Bkb
3C
3Bwb
4C
5C
††6,040 ±620 yr BP
††13,090 ±750 yr BP
††14,930 ±1,030 yr BP
†† AMS humate date
silt loam
sandy loam
loamy sand
cobble gravels
pedogenic development
pedogenic carbonate
rounded to subrounded gravels
angular to subangular gravels

Figure 30. Stratigraphy of SR-23.

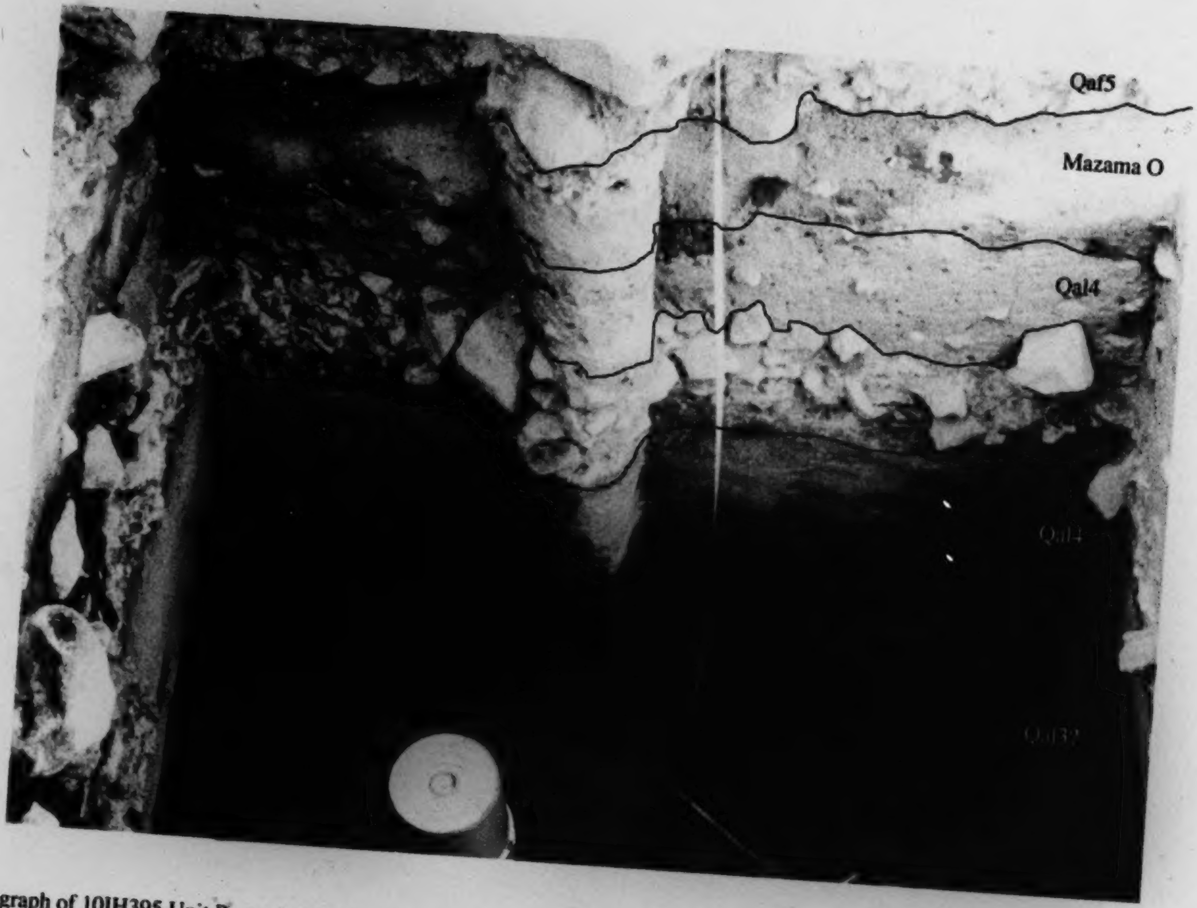

Figure 31. Photograph of 10IH395 Unit B, north wall, showing position of Middle Holocene Fan Gravels (Qaf5), redeposited Mazama O tephra, Late Pleistocene-Holocene Alluvium (Qal4), Late Pleistocene-Early Holocene Alluvial Fan Gravels (Qaf4), and alternating beds of Late Pleistocene-Early Holocene Loess (Qae3) sandy Late Pleistocene-Holocene Alluvium (Qal4), and Late Pleistocene Alluvium 2 (Qal3)(?). Mussel shell from the upper Qal4 unit produced a radiometric age of 8,360 ±80 yr BP. Soil humates from the American Bar Soil horizon developed into the upper portion of the upper Qal4 unit returned a radiometric age of 6,070 ±60 yr BP. Visible profile measures 2.5 m in depth.

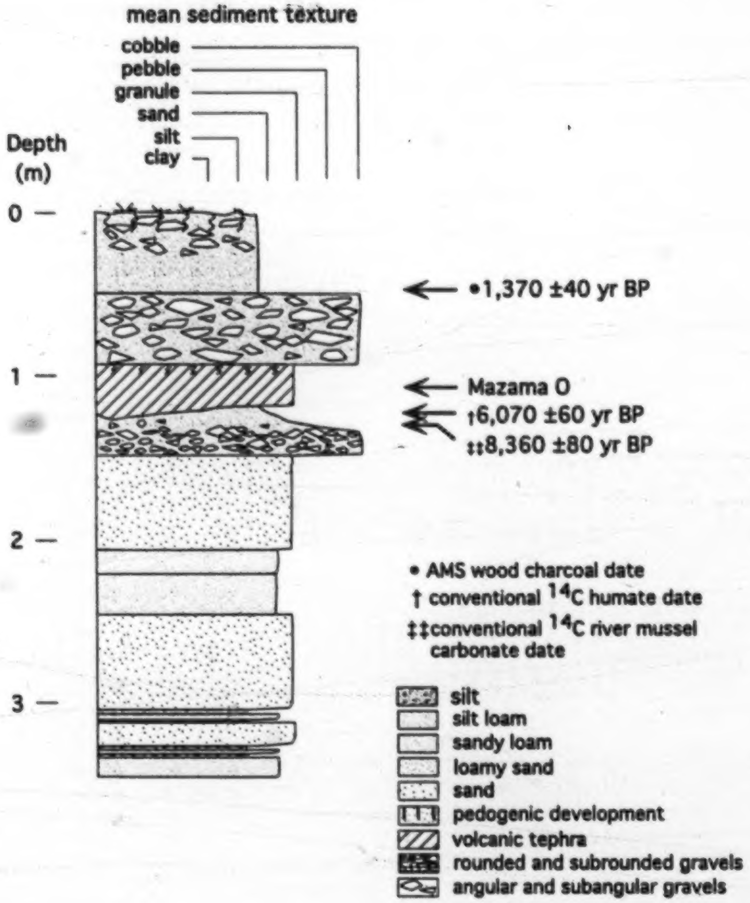
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
•1,370 ±40 yr BP
Mazama O
†6,070 ±60 yr BP
‡‡8,360 ±80 yr BP
• AMS wood charcoal date
† conventional 14C humate date
‡‡conventional 14C river mussel carbonate date
silt
silt loam
sandy loam
loamy sand
sand
pedogenic development
volcanic tephra
rounded and subrounded gravels
angular and subangular gravels

Figure 32. Stratigraphy of 10IH395, Unit B, north wall.

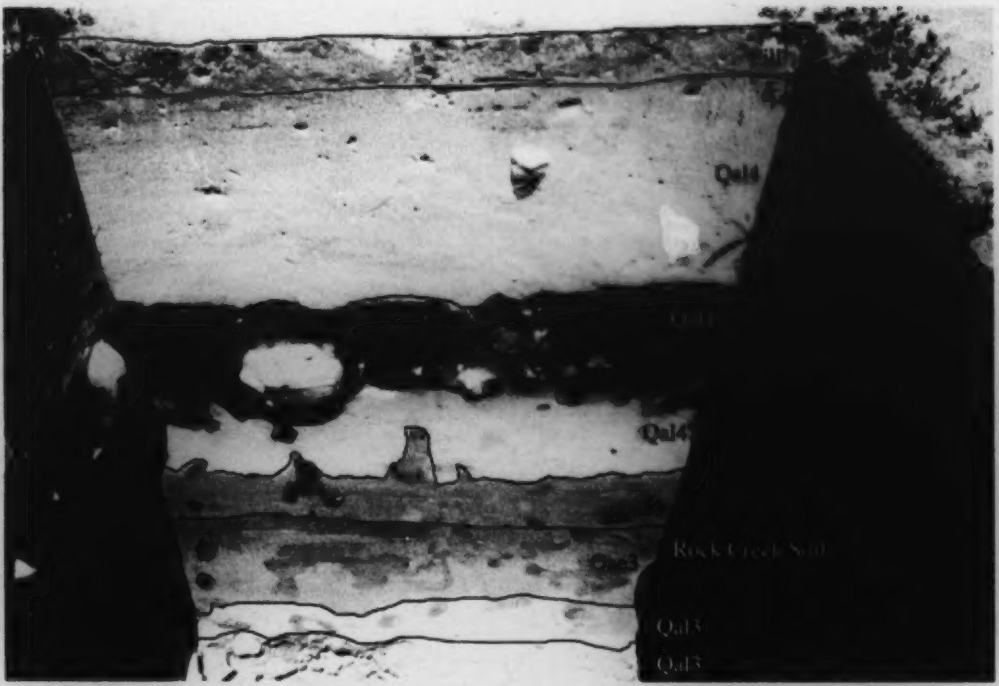
Qal4
Qal4
Qal4?
Qae3
Rock Creek Soil
Qal3
Qal3

Figure 33. Photograph of 10IH73 Unit A, north wall profile. A dark Late Pleistocene-Holocene Alluvium (Qal4) layer is bracketed by AMS charcoal dates of 8,430 ±70 yr BP above and 11,370 ±40 yr BP from an underlying Rock Creek Soil horizon. Below this dark alluvium, sandy Qal4 and sandy and gravelly Qal3 deposits alternate with Late Pleistocene-Early Holocene Loess (Qae3).

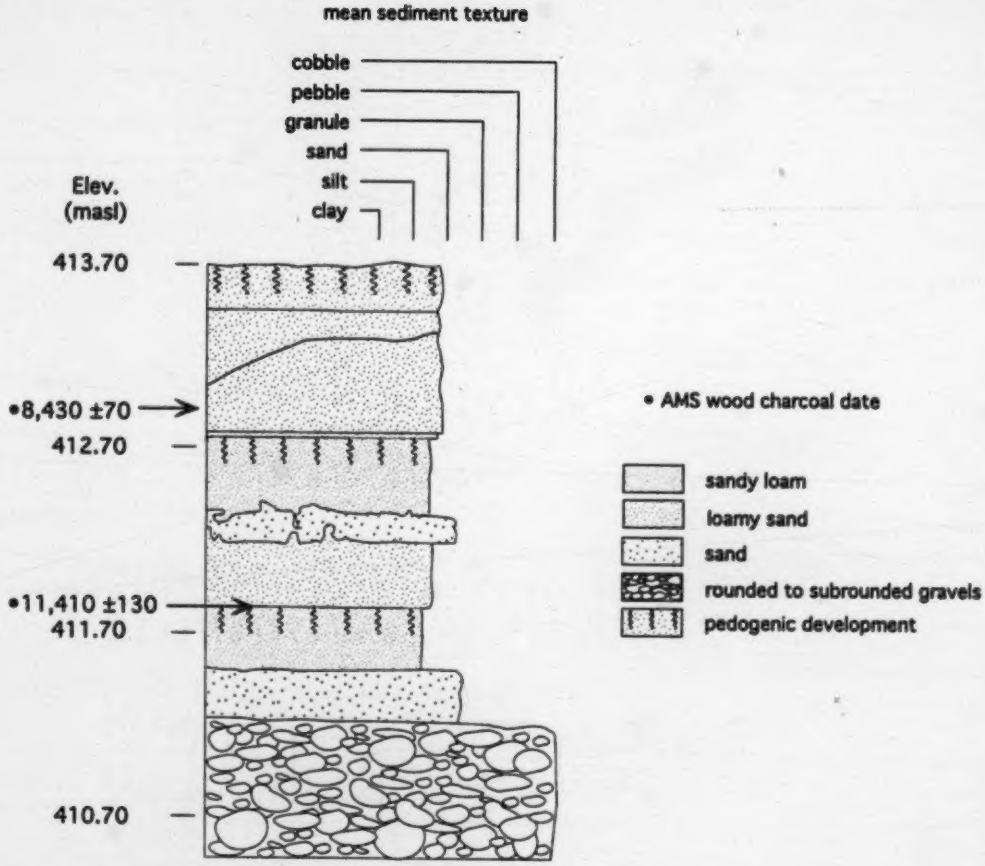
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Elev.
(masl)
413.70
•8,430 ±70
412.70
•11,410 ±130
411.70
410.70
• AMS wood charcoal date
sandy loam
loamy sand
sand
rounded to subrounded gravels
pedogenic development

Figure 34. Stratigraphy of 10IH73 Unit A

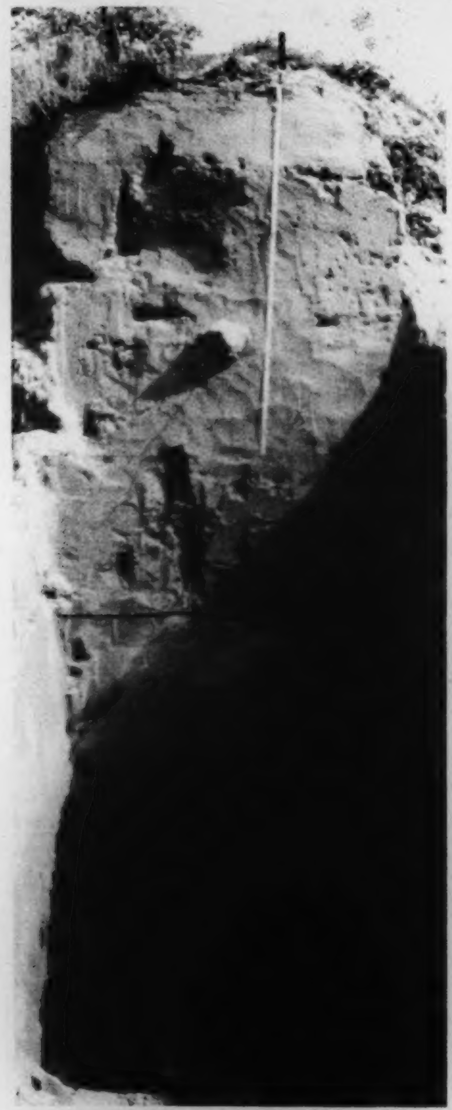

Figure 35. Photo mosaic of SR-41 profile containing Late Pleistocene Alluvium 2 (Qal3) and Late Pleistocene-Holocene Alluvium (Qal4), which are thought to provide the parent material for aeolian loess deposition at sections like SR-23.

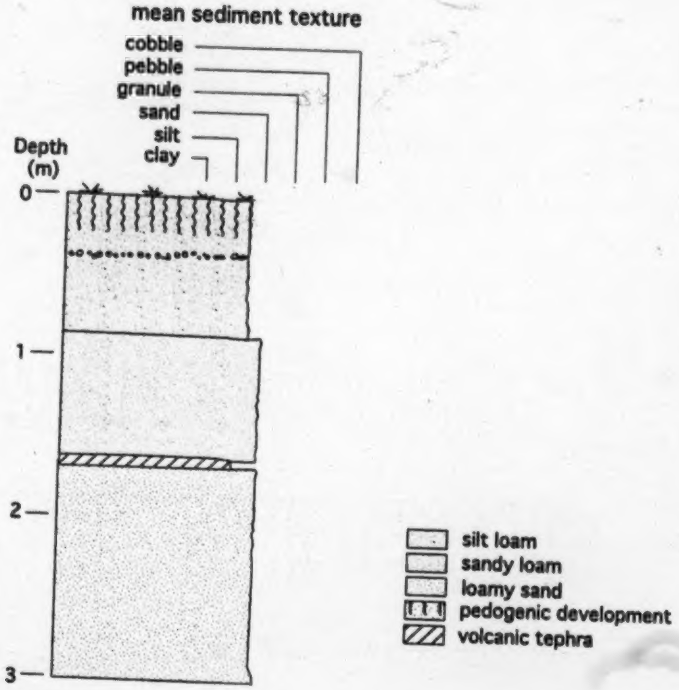
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
silt loam
sandy loam
loamy sand
pedogenic development
volcanic tephra

Figure 36. Stratigraphy of SR-41.

to aeolian deposition, alluviation apparently continued at the Hammer Creek Recreation Site following a period of downcutting sometime before 14,930 yr BP. Futhermore, the deposition of Qal3 alluvium is thought to represent the source for extensive late Pleistocene- to Holocene-age aeolian sediments seen throughout the study area.

Late Pleistocene-Holocene Alluvium (Qal4)

Description

The Late Pleistocene-Holocene Alluvium unit consists of alternating beds of silt loam to sandy loam and fine to medium quartz sand. Beds are horizontal, lack sedimentary structures, and retain clear to sharp lower boundaries. On occasion, loading structures are seen, suggesting dewatering of saturated sediments following deposition. Quartz sand deposits appear structureless, which may be a result of diagentic alteration. Often loamy and sandy deposits are vertically adjacent to one another in a stratigraphic profile.

Distribution

Sediments of the Qal4 unit are seen within the T1 terrace throughout the lower portion of the study area, at SR-13, SR-21, in archaeological sites 10IH73, 10IH1160, 10IH1220, 10IH2491, and as far downriver as 10IH395 (Figures 37-44; see also Figures 24, 25, 28, 29, 30, 31).

Origin

Magnetic susceptibility measurements on the loamy portion of Late Pleistocene-Holocene Alluvium produce high SI values relative to older alluvial units (see Appendix C). The brownish color and high susceptibility of loamy Qal4 units are considered indicators of having originated as a weathering product of iron-rich local basalts. The occurrence of the brownish Late Pleistocene-Holocene Alluvium likely reflects an increase in slope erosion of sediments derived from basaltic weathering and the deposition of these sediments as overbank sedimentation in a low-energy floodplain setting.

Age (>11,310 to 1,960 yr BP)

The age of the Late Pleistocene-Holocene Alluvium is provided by several radiocarbon dates, placing its initial formation immediately before 11,310 ±80 yr BP (TO-7358) and continuing until 1,960

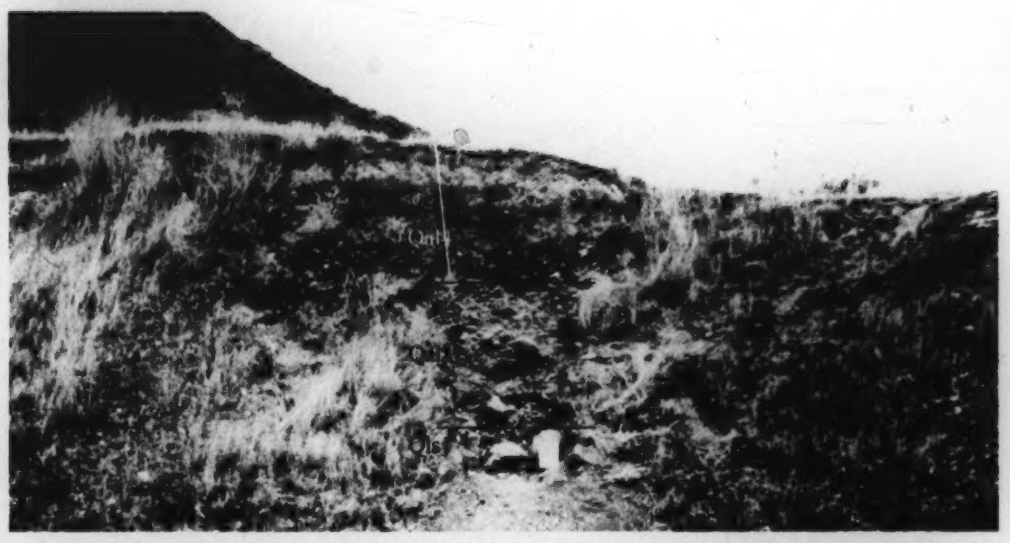

Figure 37. Overview of SR-13 section showing angular Devils Garden Slide diamict (Qls1) overlain by Late Pleistocene Alluvium 2 (Qal3) (?) and Late Pleistocene-Holocene Alluvium (Qal4). Measuring stick 2.0 m long.

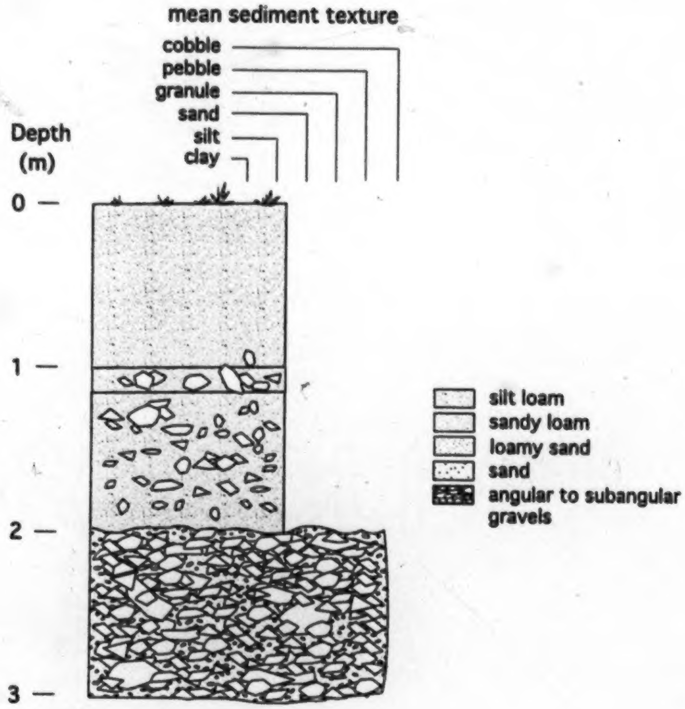
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
silt loam
sandy loam
loamy sand
sand
angular to subangular gravels

Figure 38. Stratigraphy of SR-13.

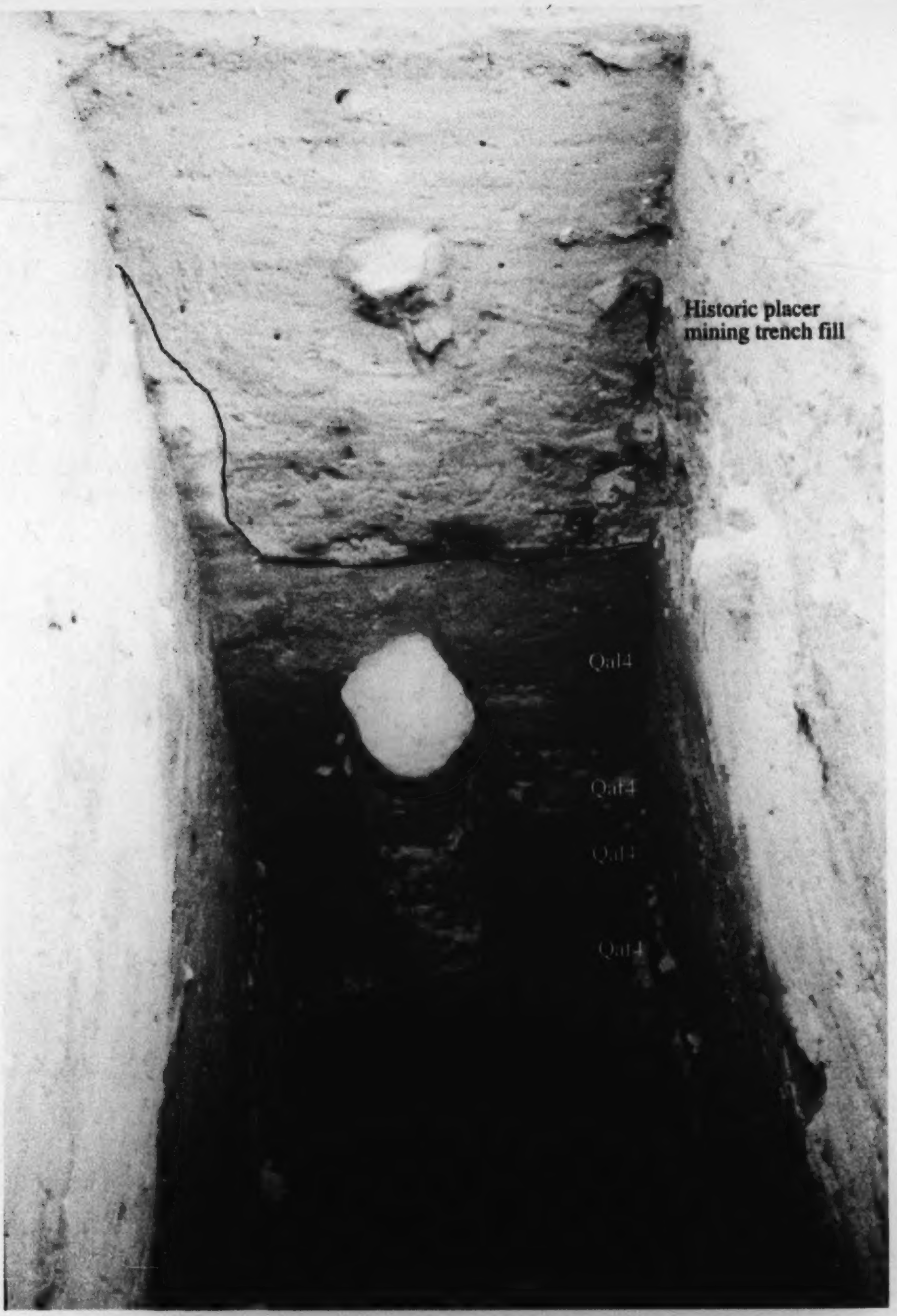
Historic placer mining trench fill
Qal4
Qal4
Qal4
Qal4

Figure 39. Photograph of 10IH1160 Unit G, west wall. Note sharp contact between disturbed fill produced during historic placer mining activity and underlying undisturbed Late Pleistocene-Holocene Alluvium (Qal4) deposits. Profile is about 3.7 m tall.

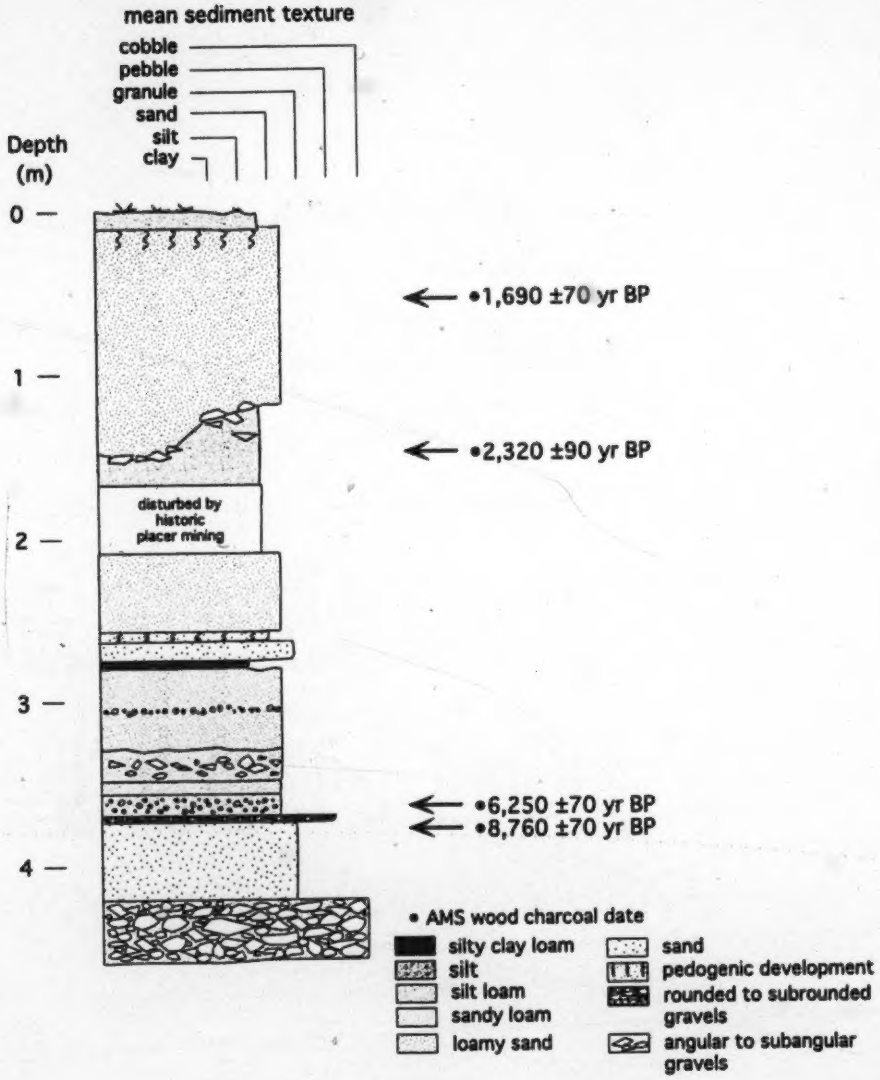
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
•1,690 ±70 yr BP
•2,320 ±90 yr BP
disturbed by historic placer mining
•6,250 ±70 yr BP
•8,760 ±70 yr BP
• AMS wood charcoal date
silty clay loam
silt
silt loam
sandy loam
loamy sand
sand
pedogenic development
rounded to subrounded gravels
angular to subangular gravels

Figure 40. Composite stratigraphy of 10IH1160 Unit D and Unit G profiles.

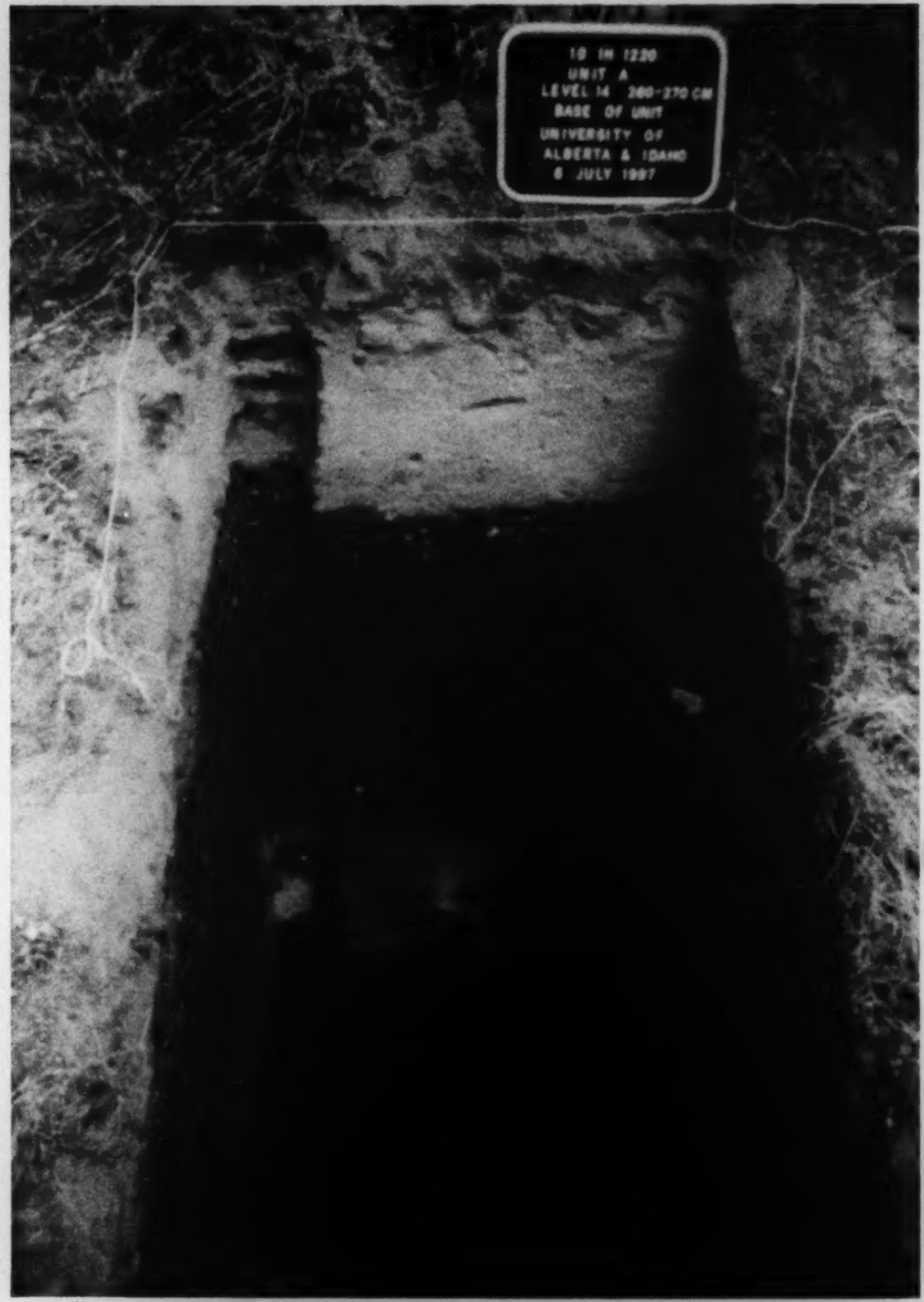
10 IH 1220
UNIT A
LEVEL 14 260-270 CM
BASE OF UNIT
UNIVERSITY OF
ALBERTA & IDAHO
6 JULY 1997

Figure 41. Photograph of 10IH1220 Unit A, north wall. Base of profile shows Late Pleistocene-Holocene Alluvium (Qal4) overlain by light colored Mazama O tephra, which is covered, in turn, by a return to Qal4 deposition. AMS dates of humates from sediment positioned below the tephra layer produced an age of 9,170 ±180 yr BP. Charcoal recovered just above the tephra layer returned an age of 3,070 ±50 yr BP.

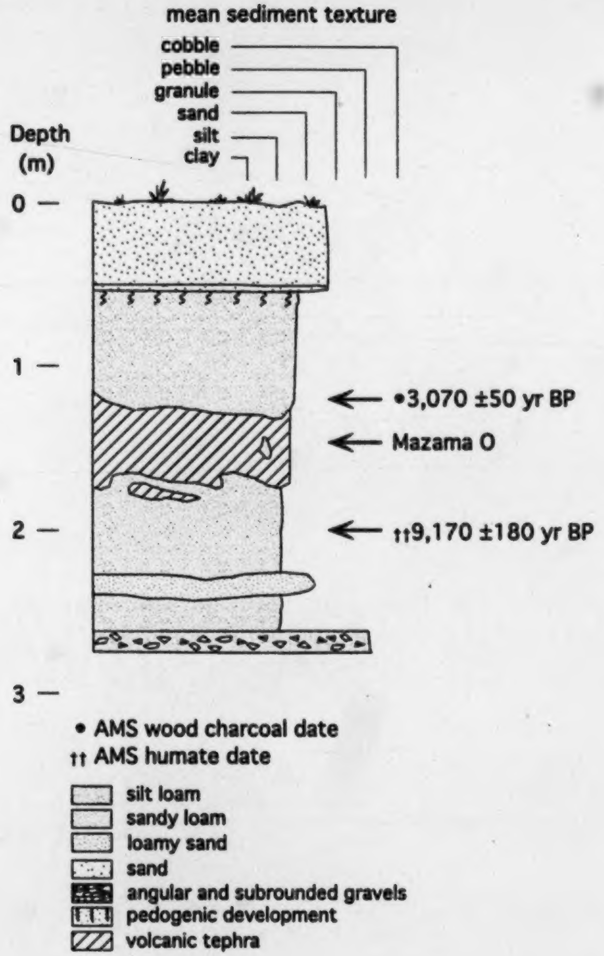
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
•3,070 ±50 yr BP
Mazama O
††9,170 ±180 yr BP
• AMS wood charcoal date
†† AMS humate date
silt loam
sandy loam
loamy sand
sand
angular and subrounded gravels
pedogenic development
volcanic tephra

Figure 42. Stratigraphy of 10IH1220 Unit A, north wall.

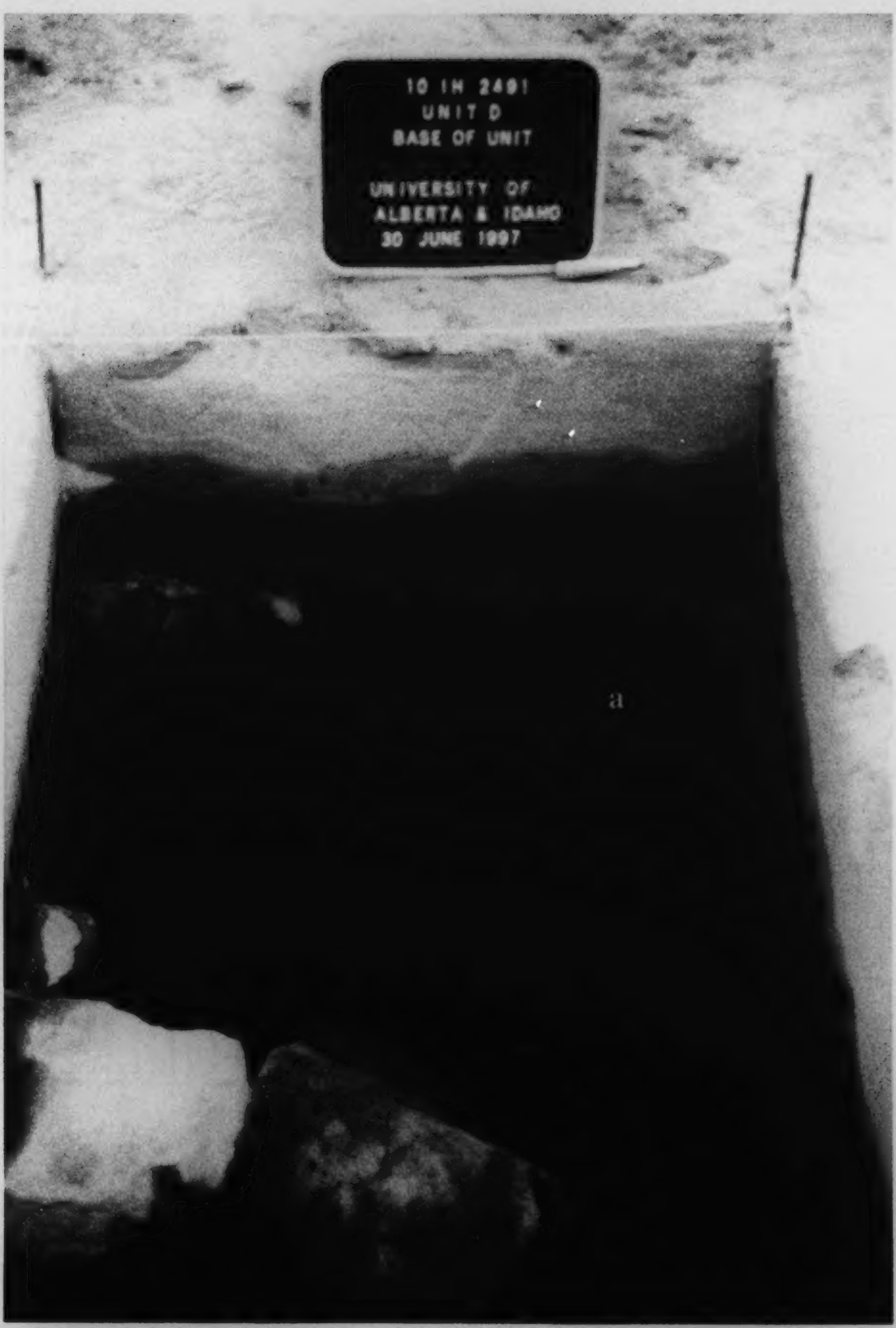
10 IH 2491
UNIT D
BASE OF UNIT
UNIVERSITY OF
ALBERTA & IDAHO
30 JUNE 1997
a

Figure 43. Photograph of 10IH2491 Unit D, west wall. Fine Late Pleistocene-Holocene Alluvium (Qal4) overlies reworked Devils Garden Slide diamict clasts. A redeposited layer of Mazama O tephra (a) is bracketed by AMS charcoal dates of 1,960 ±40 and 2,010 ±40 yr BP. Charcoal found near the bottom of Unit D dated to 6,780 ±50 yr BP.

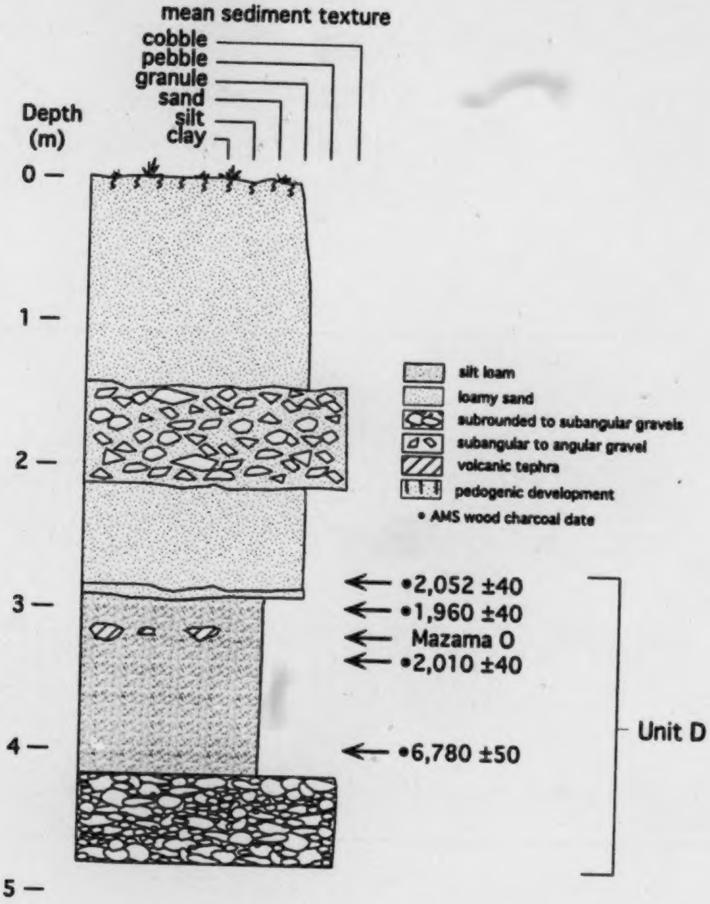
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
silt loam
loamy sand
subrounded to subangular gravels
subangular to angular gravel
volcanic tephra
pedogenic development
• AMS wood charcoal date
•2,052 ±40
•1,960 ±40
Mazama O
•2,010 ±40
•6,780 ±50
Unit D

Figure 44. Stratigraphy of 10IH2491 Unit D, west wall and overlying sediments

±40 yr BP (Beta-114808). In some sections the deposition of this unit is largely continuous; however, others retain evidence of erosional unconformities and periods of soil formation.

Paleosol on the Late Pleistocene-Holocene Alluvium (Qal4) -- American Bar Soil

Pedogenic alteration of Qal4 sediments is seen at only one locality in the study area. At the American Bar site (10IH395) an eroded paleosol with Bkb and Btb horizons developed in a Qal1 deposit. This soil is a brown (10YR4/3) silty clay loam, with moderately developed coarse angular blocky structure, extensive clay skins and common filaments of calcium carbonate. A conventional radiocarbon date on the humate fraction of this paleosol produced an age of 6,070 ±60 yr BP (Tx-9138), whereas river mussel shells recovered within the same stratigraphic unit dated to 8,360 ±80 yr BP (Tx-9269). The spread between the two dates is interpreted as representing the difference in timing between pedogenic alteration and alluvial deposition, respectively. Therefore, the American Bar Soil is considered to represent middle Holocene pedogenic development.

Late Holocene Alluvium (Qal5)

Description

The Late Holocene Alluvium unit consists of alternating beds of sand, silt and clay, in what appears to represent several fining-upwards floodplain depositional sequences. In other areas, alluvial deposition appears as a point bar deposits with massive immature sand and loamy sand textures.

Distribution

The Qal5 unit is seen on the TO terrace at heights up to 7.6 m (25') above the modern channel of the Salmon River. This unit is seen in stratigraphic exposures at the Hammer Creek Recreation Site (HC-2), Pine Bar, and at the Nipeheme Village site (10IH1312) (Figures 45-48). Much of this deposit was destroyed in the study area by historic placer mining, which removed the fine-textured alluvium in order to gain access to the underlying gravel deposits.

Origin

Textural analyses and bedding structures observed within these sediments point to an alluvial origin. The deposition of fining-upwards sequences of sediments are attributed to overbank flooding

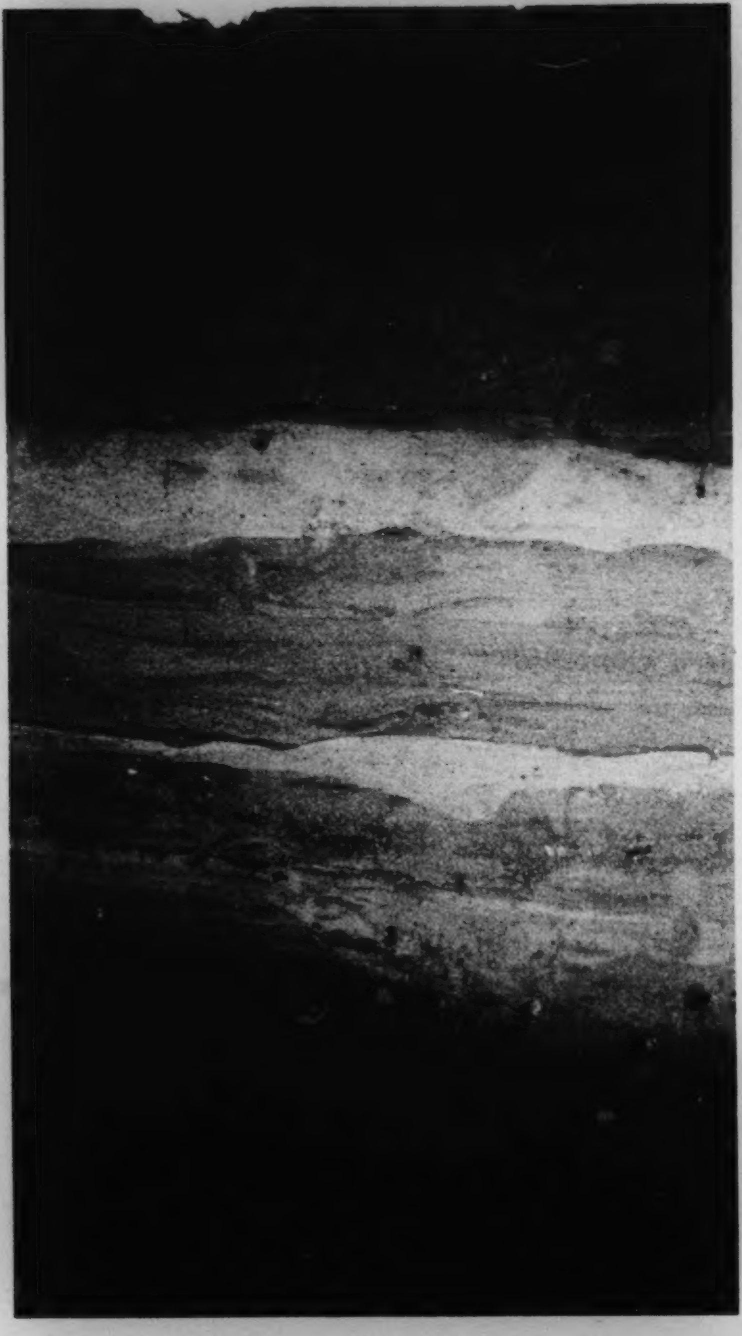

Figure 45. Photograph of the upper portion of the HC-2 section. Bedded Late Holocene Alluvium (Qal5) deposits are overlain by a highly organic plaggen soil horizon produced in a historic stockyard. An AMS date of 1,780 ±50 yr BP was returned from charcoal found within the Qal5 unit 93 cm below the surface.

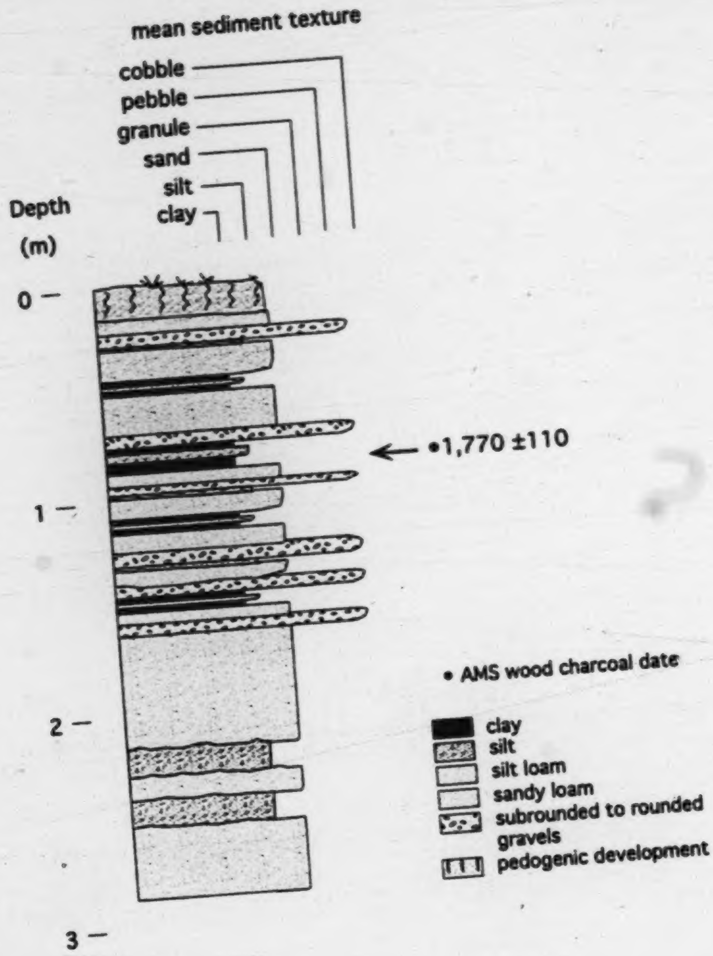
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
•1,770 ±110
• AMS wood charcoal date
clay
silt
silt loam
sandy loam
subrounded to rounded gravels
pedogenic development

Figure 46. Stratigraphy of HC-2.

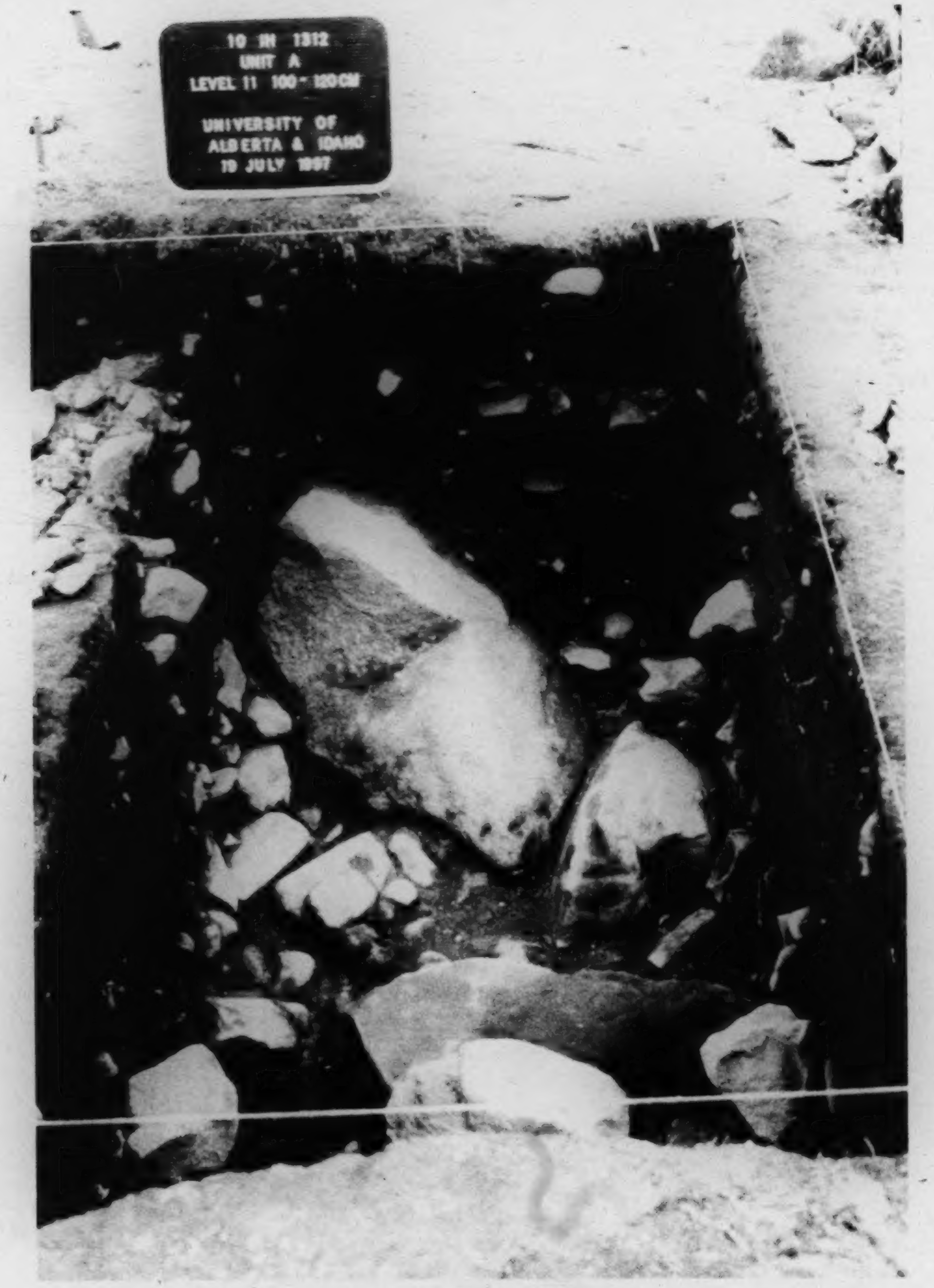
10 IH 1312
UNIT A
LEVEL 11 100 - 120CM
UNIVERSITY OF
ALBERTA & IDAHO
19 JULY 1997

Figure 47. Photograph of 10IH1312 Unit A, east wall. Late Pleistocene-Holocene Alluvium (Qal4) overlies basaltic gravel derived from the Devils Garden diamict (Qls1). Deposition of Qal4 here post-dates a 3,610 ±60 yr BP AMS date of river mussel shell.

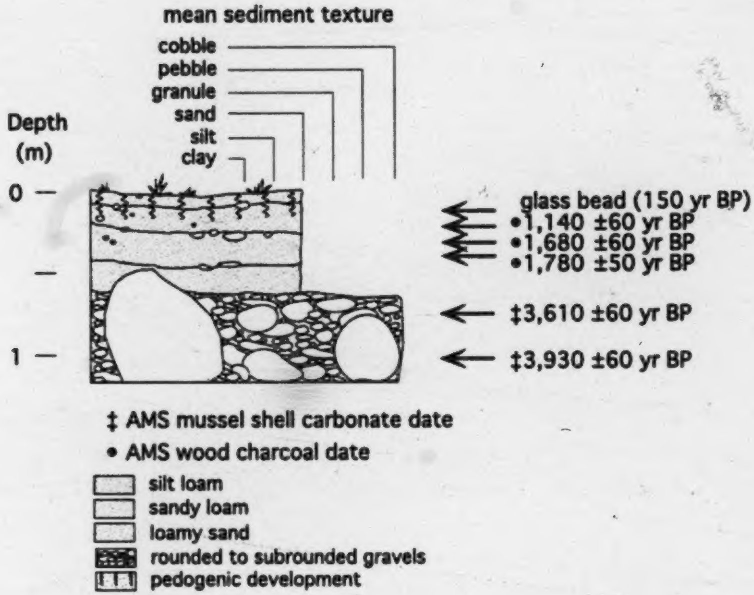
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
glass bead (150 yr BP)
•1,140 ±60 yr BP
•1,680 ±60 yr BP
•1,780 ±50 yr BP
‡3,610 ±60 yr BP
‡3,930 ±60 yr BP
‡ AMS mussel shell carbonate date
• AMS wood charcoal date
silt loam
sandy loam
loamy sand
rounded to subrounded gravels
pedogenic development

Figure 48. Stratigraphy of 10IH1312 Unit A, east wall.

episodes wherein rising waters initially erode older floodplain sediments, followed by increasingly-finer sediment deposition as flood discharge wanes. The fine resolution of the Late Holocene Alluvium stratigraphy appears to be unique to this unit (particularly as revealed in the HC-2 profile (Figures 45 and 46)).

Age (<1,960 yr BP to ~AD 1974)

Deposition of the Late Holocene Alluvium unit occured after 1,960 yr BP and continues today, established on the basis of inclusive archaeological components and radiocarbon dates. The last period of Late Holocene Alluvium deposition probably occurred during the 1974 flood, which reached a discharge of ca. 3,681.6 cms (ca. 130,000 cfs) and inundated the T0 terrace in many parts of the study area.

Modern Soil Development on the Late Holocene Alluvium (Qal5)

Because alluviation continued on the T0 terrace since 2,000 yr BP, pedogenic development is weakly developed, where observed. Soil development is largely restricted to a measurable degree of rubification, and organic matter that is higher than unaltered Qal5 deposits. At the Hammer Creek Recreation Site, an Ao horizon was observed in the profile of HC-2, which reflected historic use of the area for cattle stockyards.

Aeolian Deposits

Fine textured, massive or weakly bedded deposits with granulometric distributions dominated by very fine sand and silt, and relatively high carbonate content are seen in many areas of the canyon. These deposits often retain angles of repose in excess of seven degrees and typically retain the geometry of underlying deposits as they blanket landforms. Four aeolian deposits were identified in the study area, and presented here in order of decreasing age. Chronological control for these units is provided by radiocarbon dates and inclusive volcanic tephras (Appendix A and E).

Late Pleistocene Loess 1 (Qae1)

Description

Thick deposits of silt loam to loamy sand sediment with massive to subangular blocky structure, common to abundant calcium carbonate filaments and occasional carbonate concretions are seen in many parts of the study area. Lacking internal bedding structures, the Qae1 drapes landforms in various forms, reflecting the geometry of underlying deposits.

Distribution

The Qae1 unit is seen in the upper portion of the study area at SR-26-3 and SR-26-4 (Figure 49, see also Figure 23). The unit is normally confined to the T2 terrace or seen as a component of larger alluvial fans, at elevations up to ca. 60 m (ca. 195') above the present channel of the Salmon River. The deposit ranges between ca. 4 and 0.80 m in thickness.

Origin

Based on its texture, degree of sorting, carbonate content, and lack of internal bedding structure, the Qae1 unit is defined as aeolian in nature. These deposits are probably derived from fine overbank sediments, which were reworked upslope by aeolian processes during dry climatic periods.

Age (<60-70 ka to >25,000 yr BP)

At SR-26-3, the deposition of the Late Pleistocene Loess 1 predates soil development at ca. 25,270 yr BP, based on a conventional humate date, but before the deposition of the CB-11 and CB-12 tephras at ca. 60 to 70 ka (Sarna-Wojcicki, written communication 1999). An upper limiting age for this loess is provided only by the presence of an AMS date on wood charcoal from a paleosol in the upper portion of SR-26-5 (Figures 50-52). Given the stratigraphic separation from this radiocarbon date and the top of the Qae1 unit, this is a very imprecise minimum age estimate. The China Gardens Soil is seen stratigraphically above the Late Pleistocene Loess 1 at SR-26-5 and provides an upper temporal boundary. Although not directly dated, the China Gardens Soil is thought to be a possible local equivalent to the Washtucna Soil of eastern Washington, which has an upper limiting age of 18,000 yr BP (McDonald and Busacca 1988; Busacca and McDonald 1994).

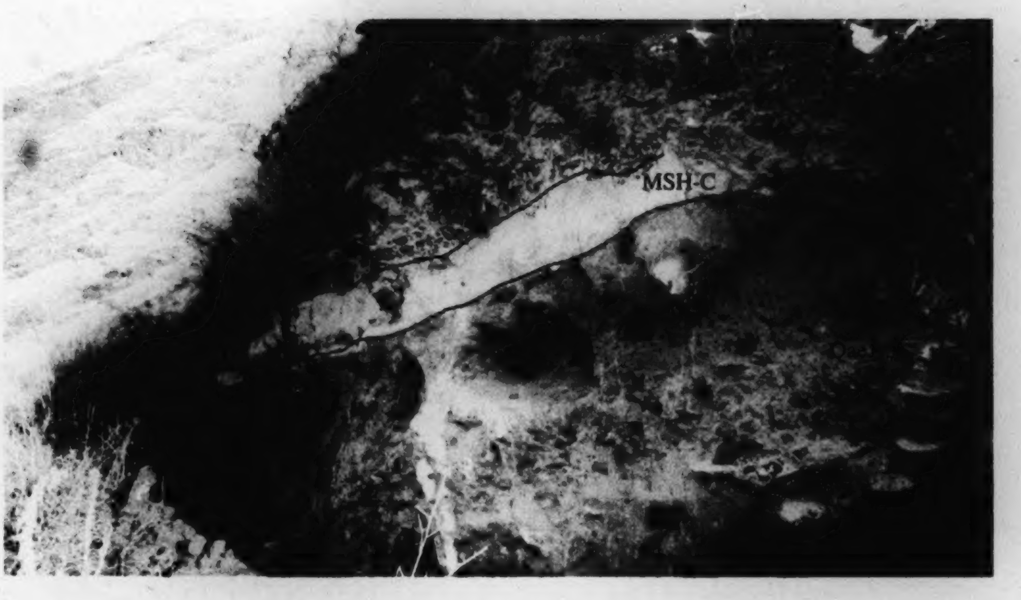

Figure 49. Closer view of SR-26-4 stratigraphy showing position of MSH-C tephra over Late Pleistocene Loess 1 (Qae1).

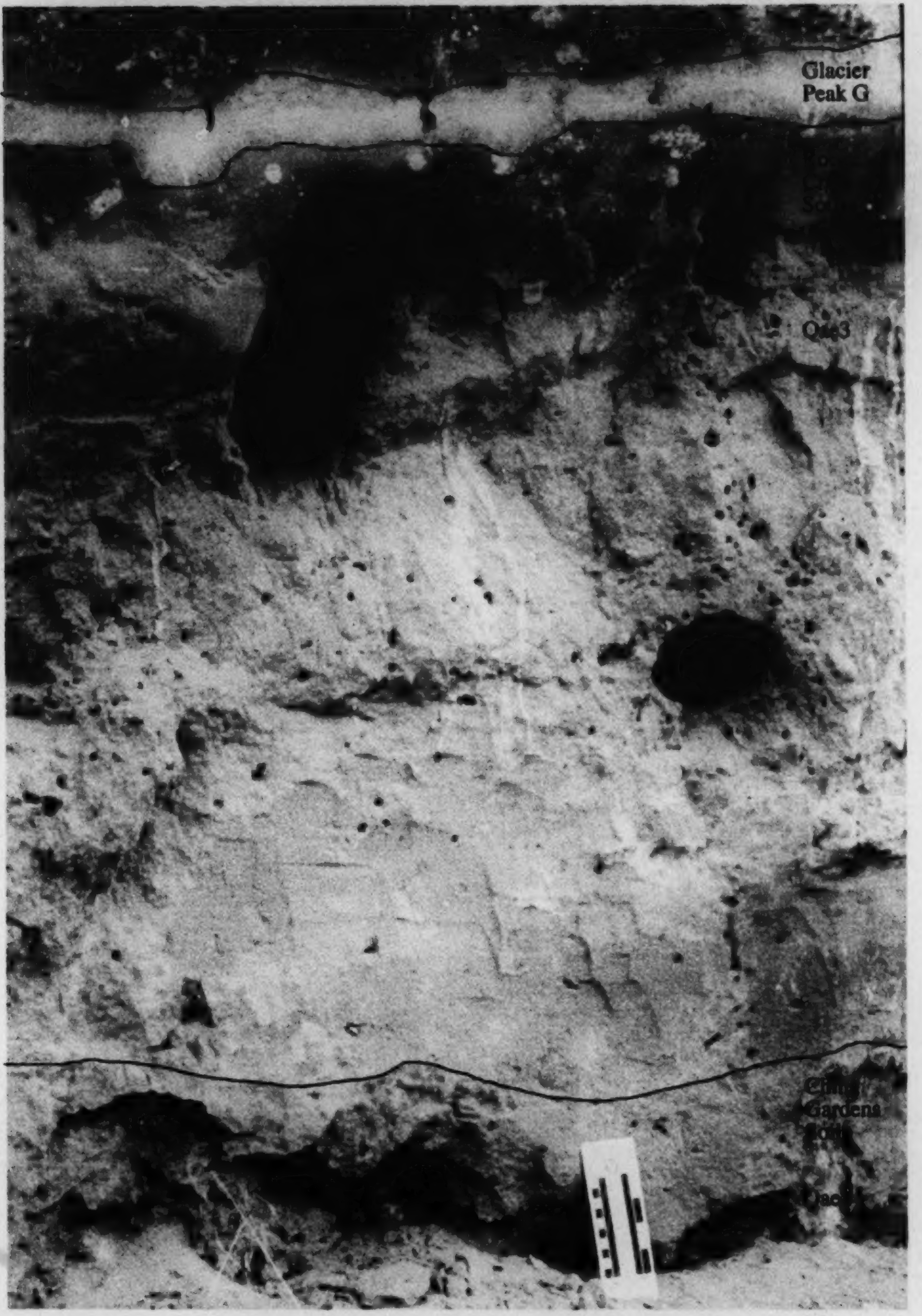

Figure 50. Photograph of the SR-26-5 section, showing position of white tephra layers identified as Glacier Peak set G. Tephra immediately overlies position of Rock Creek Soil layers, which are associated with two AMS charcoal dates of 10,740 and 11,320 yr BP. Slightly darker sediment at base of profile marks the increased rubification of the China Gardens Soil. Scale bar on left is 10 cm long.

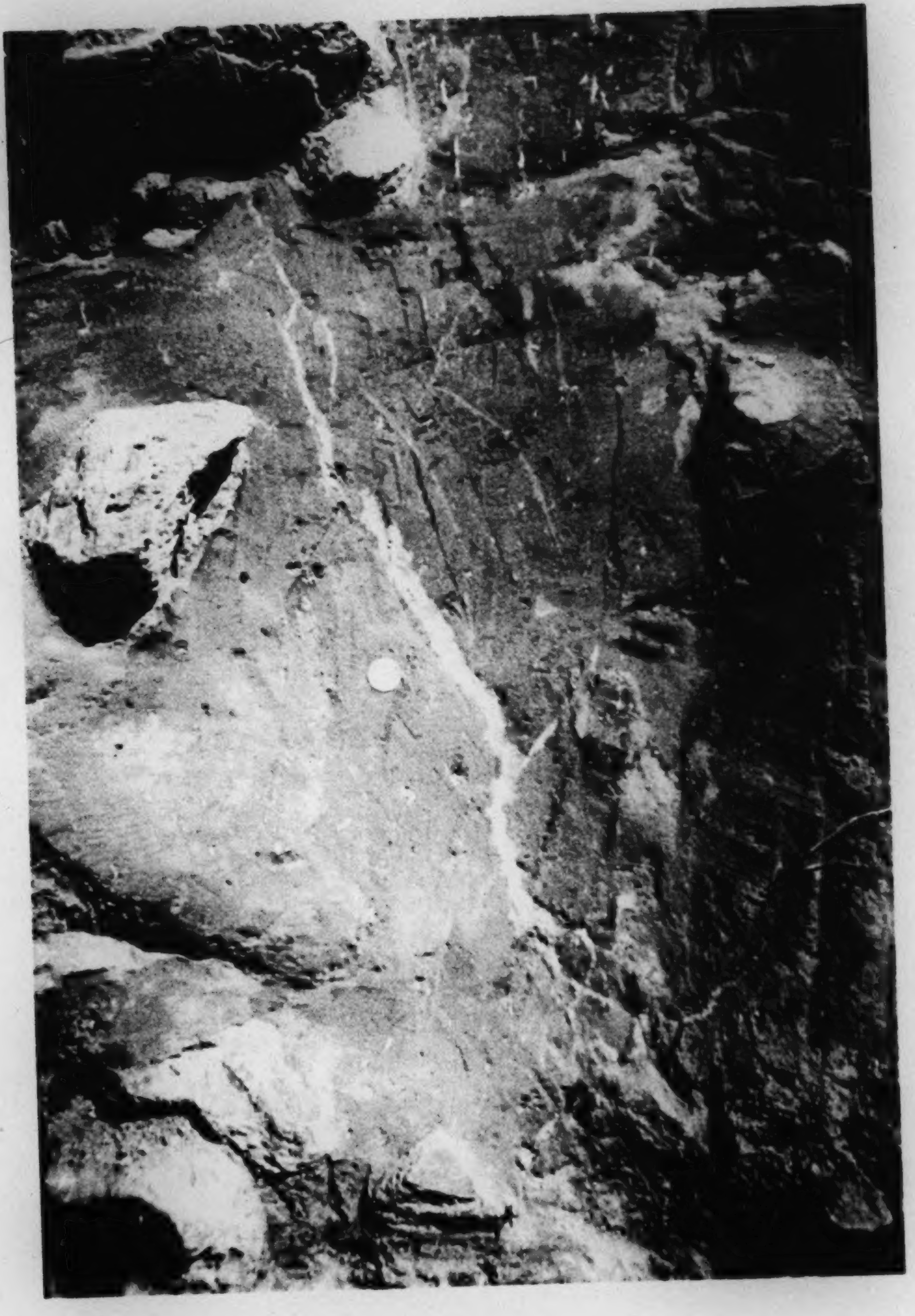

Figure 51. Possible sand-infilled desiccation crack extending downward from surface of China Gardens Soil at SR-26-5. Quarter provided for scale at left of crack.

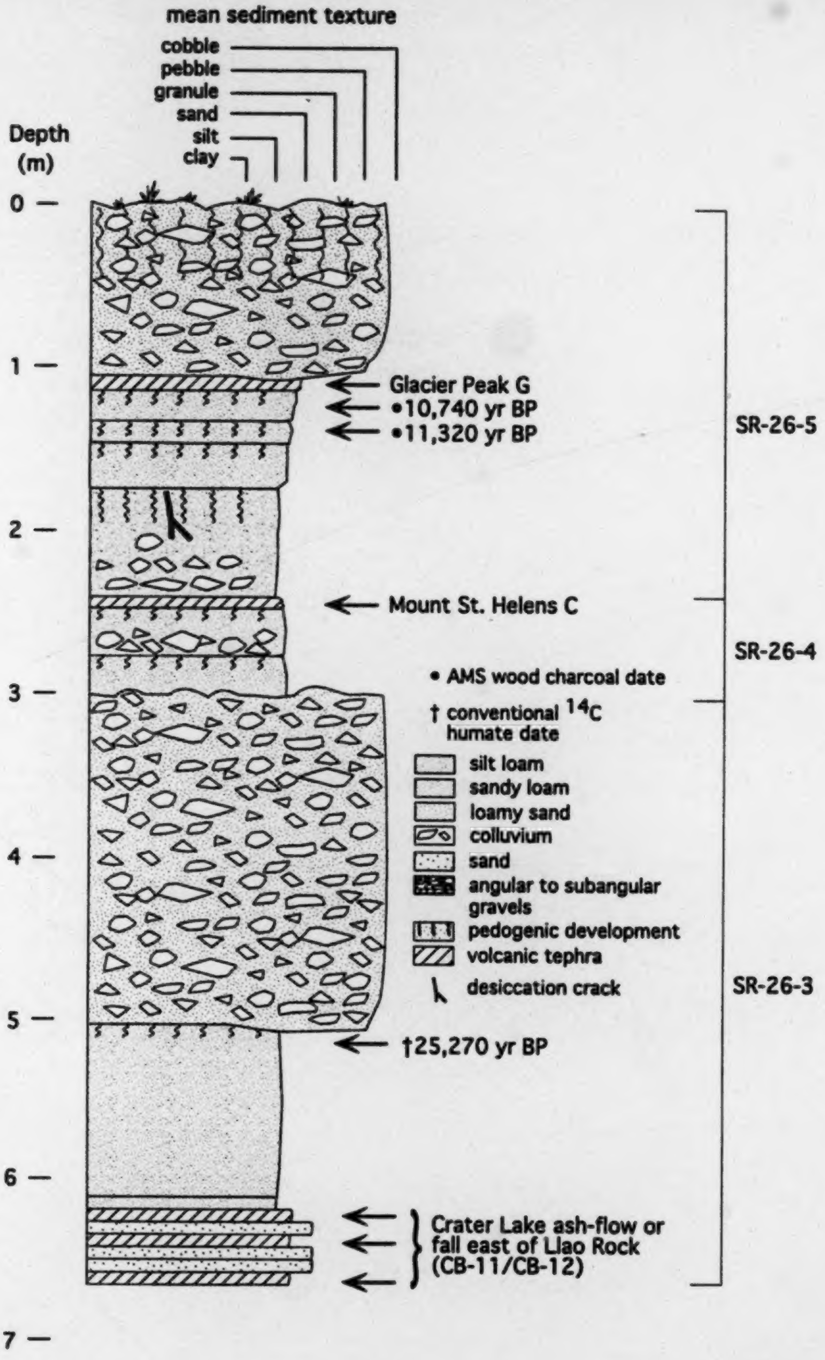
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
6
7
Glacier Peak G
•10,740 yr BP
•11,320 yr BP
Mount St. Helens C
†25,270 yr BP
Crater Lake ash-flow or fall east of Llao Rock (CB-11/CB-12)
• AMS wood charcoal date
† conventional ¹⁴C humate date
silt loam
sandy loam
loamy sand
colluvium
sand
angular to subangular gravels
pedogenic development
volcanic tephra
desiccation crack
SR-26-5
SR-26-4
SR-26-3

Figure 52. Composite stratigraphy of SR-26, showing relative position of SR-26-5, SR-26-4, and SR-26-3 sections.

Paleosol on the Late Pleistocene Loess 1 -- Lyons Bar Soil

Pedogenic alteration of the Qae1 unit is represented at SR-26-4 and SR-26-3 in three distinct pedogenic horizons between 447.93 masl (1469.6 fasl) and 444.66 masl (1458.8 fasl). This paleosol complex is named the Lyons Bar Soil (being first identified at Lyons Bar, near RM 49.5) and is defined by light yellowish brown (10YR6/4) to yellowish brown (10YR5/4) soil colors, weakly-developed subangular blocky structure, and common calcium carbonate stringers and filaments. The upper limits of the Lyons Bar Soil horizons at SR-26 are truncated by erosional unconformities. Pedogenic development of the Lyons Bar Soil apparently recurred during a period of occasional surficial instability at SR-26. Potentially, this soil might be found in the Lower Salmon River Canyon as a single pedogenic horizon, where geomorphic conditions allowed for greater surficial stability.

Late Pleistocene Loess 2 (Qae2)

Description

This unit consists of beds of loamy sediment with occasional angular to subangular clasts derived from adjacent slopes or alluvial fans. In many areas, the original parent material was greatly altered by pedogenic development. Vertically-oriented sand-infilled desiccation cracks penetrate from the surface of this unit in one location (SR-26-5) (see Figure 51).

Distribution

The Late Pleistocene Loess 2 unit is found mainly in the upper portion of the study area, seen in the T2 terrace in sections SR-26-5, SR-27, SR-34 and SR-35, where placer mining provided large exposures; however a limited distibution of Qae2 deposits is thought to be found at SR-22 downriver (Figures 53-63, see also Figures 50 and 52). This stratigraphic unit is found at elevations up to 24 m (79') above the modern Salmon River channel.

Origin

As with the Qae1 unit, the texture, lack of bedding structure, calcium carbonate content and color all point to an aeolian mechanism of deposition. The Qae2 deposit probably formed in the manner typical

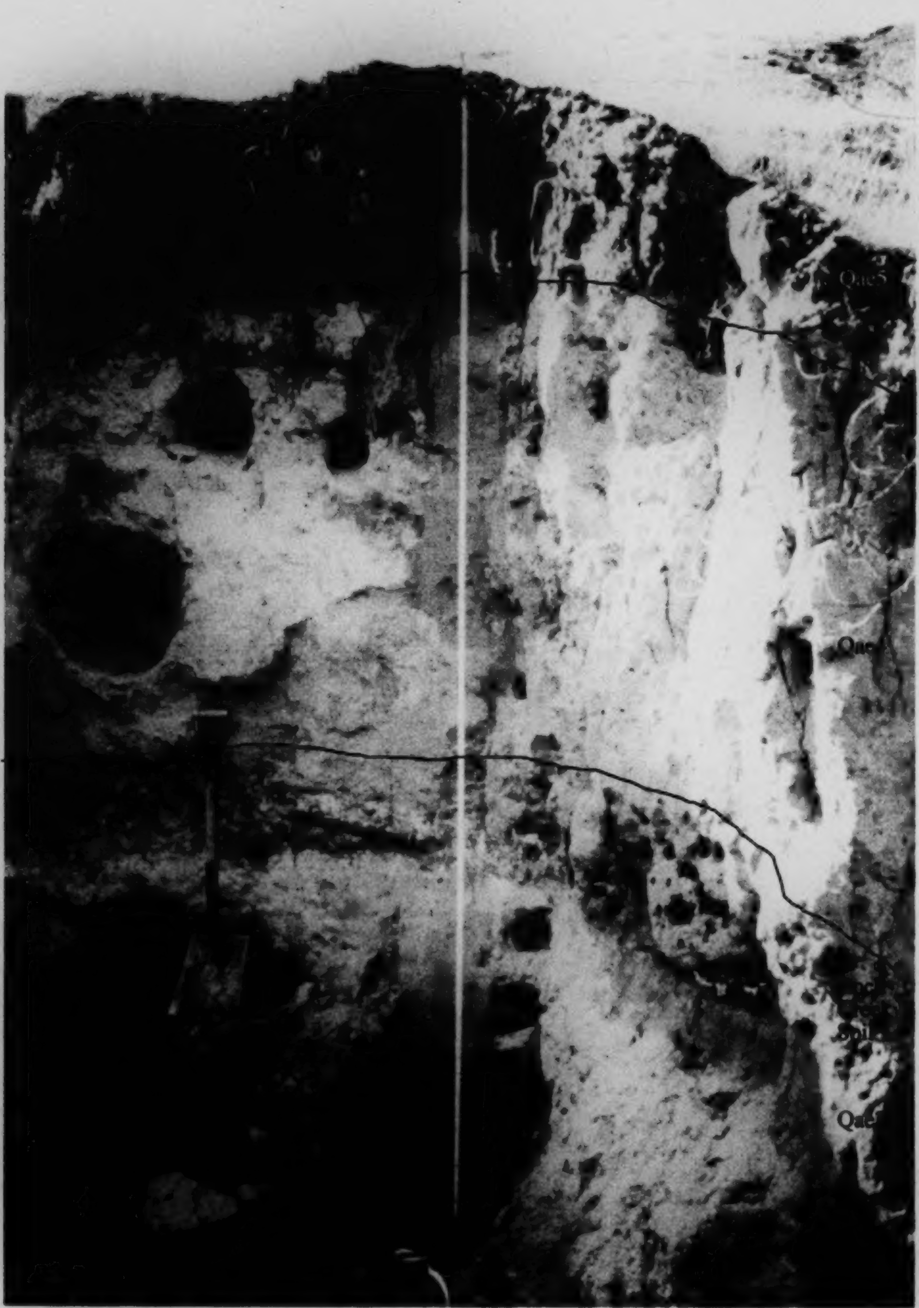

Figure 53. Photograph of SR-27 section. Note calcareous Rock Creek Soil just below metal handle of shovel. Soil humates returned an AMS date of 12,220 ±310 yr BP from this paleosol horizon. Shovel is ca. 90 cm tall.

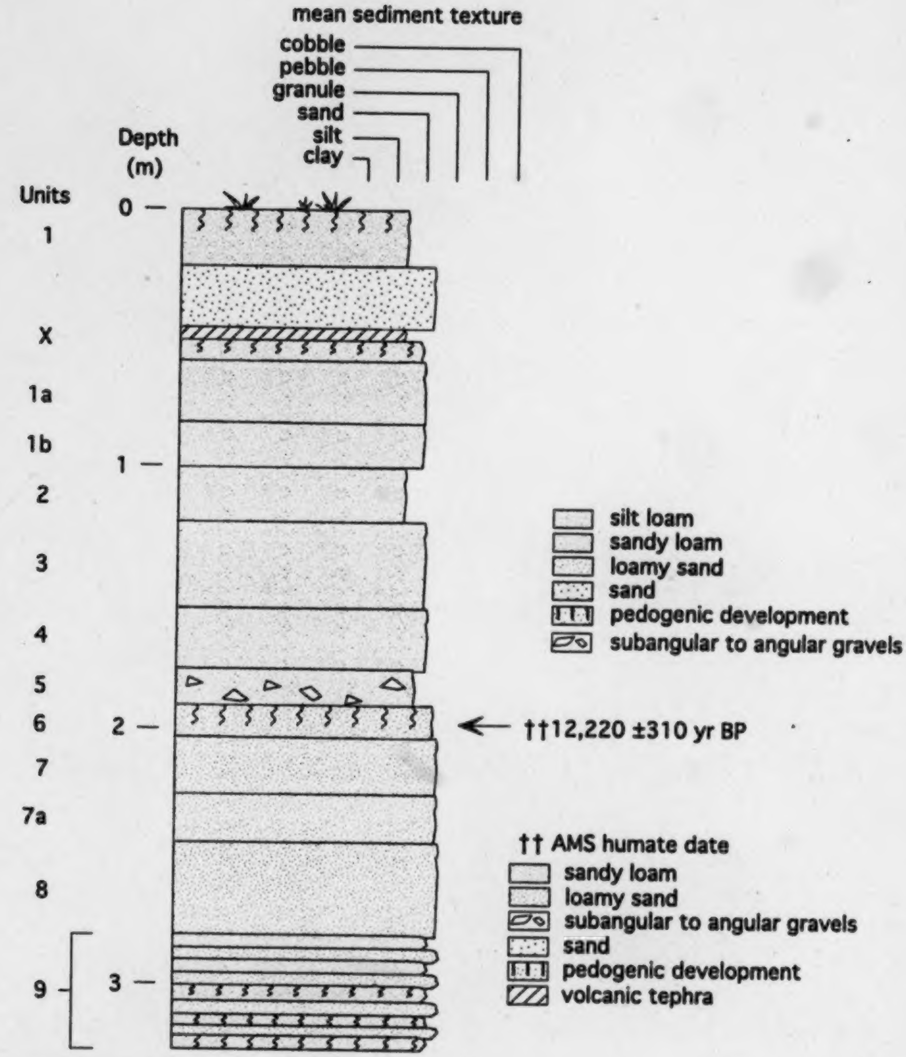
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
Units
0
1
X
1a
1b
1
2
3
4
5
6
2
7
7a
8
9
3
silt loam
sandy loam
loamy sand
sand
pedogenic development
subangular to angular gravels
††12,220 ±310 yr BP
†† AMS humate date
sandy loam
loamy sand
subangular to angular gravels
sand
pedogenic development
volcanic tephra

Figure 54. Stratigraphy of SR-27.

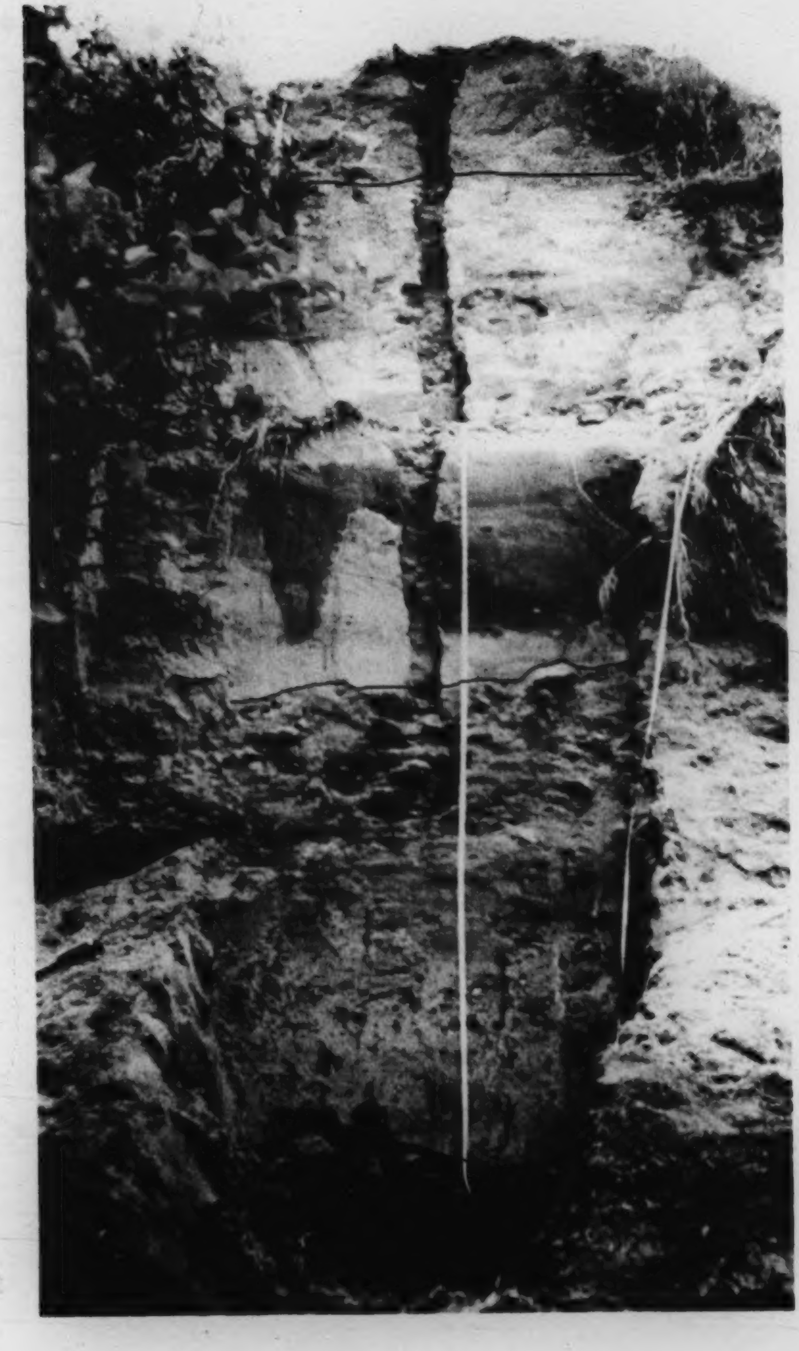
Qae5
Qae4
Rock Creek
Soil Horizon
Qae3
Qaf3?

Figure 55. Photograph of SR-34 section. Profile is 5.5 m tall.

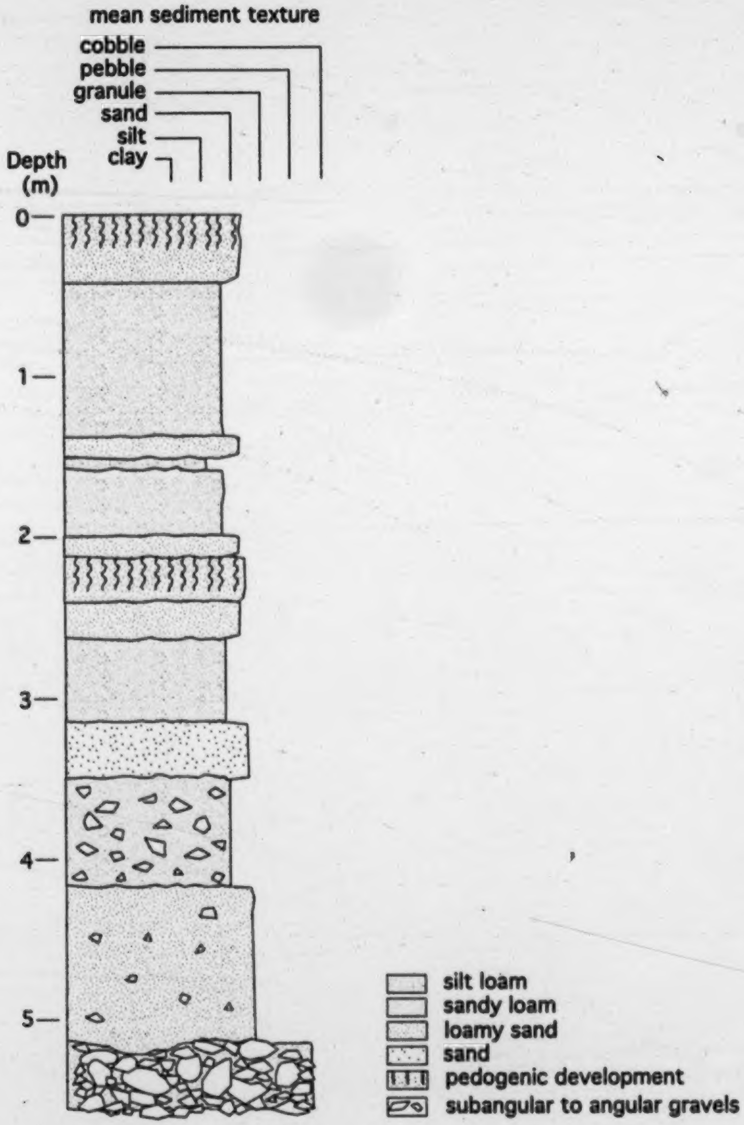
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
silt loam
sandy loam
loamy sand
sand
pedogenic development
subangular to angular gravels

Figure 56. Stratigraphy of SR-34.

Figure 57. Overview of Hammer Creek Recreation Site in upper portion of study area, showing position of SR-35 section. View is to the west.

Figure 58. Overview of SR-35 section.

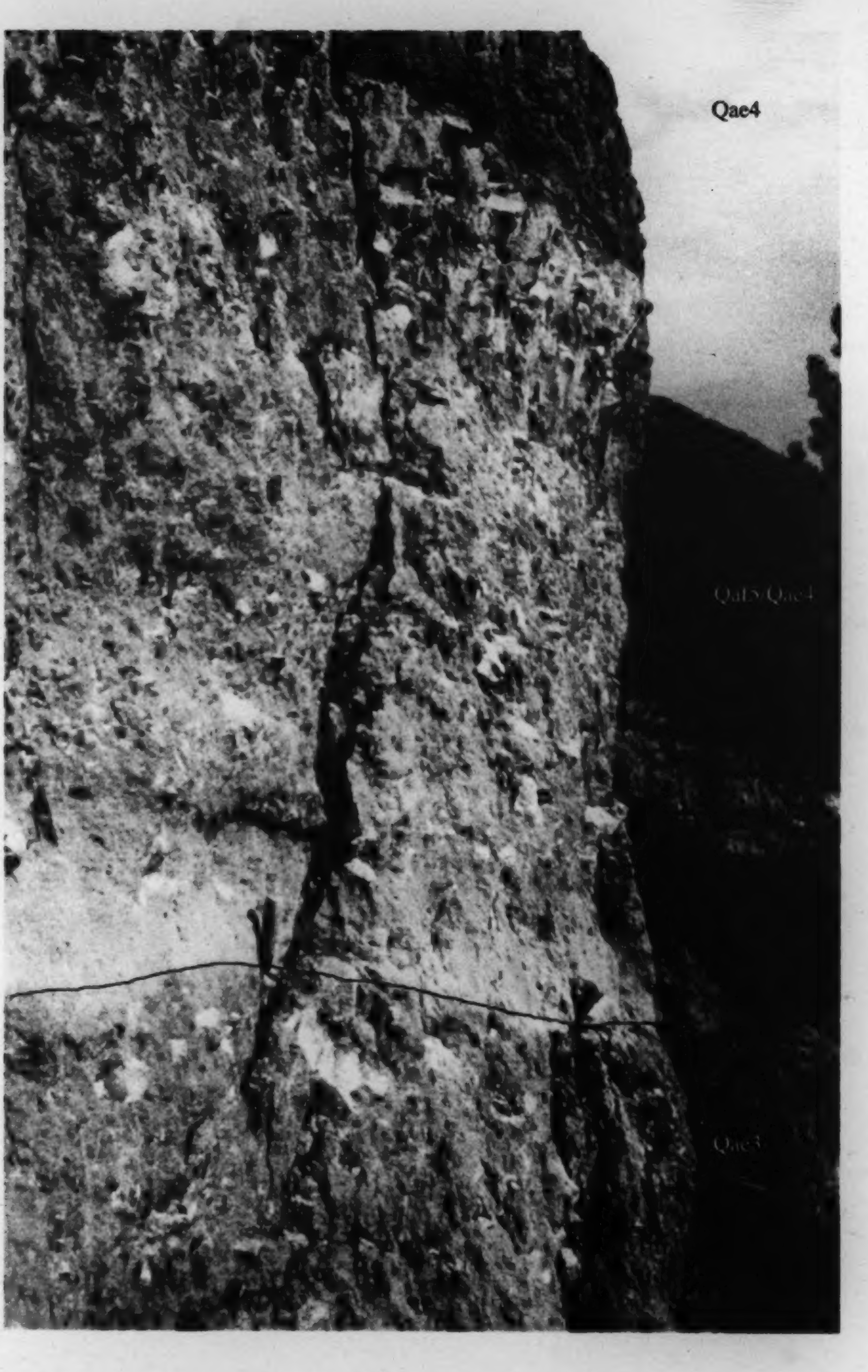

Figure 59. Closeup of middle portion of SR-35 stratigraphic section, showing poorly sorted Middle Holocene Alluvial Fan Gravels (Qaf5) mixed with Middle Holocene Sandy Loess (Qae4). Light coloration marks petrocalcic feature associated with American Bar Soil development. This paleosol is bracketed above by an AMS date of 5,670 ±80 yr BP and below by an AMS date of 8,410 ±650 yr BP. Handle of trowel is 10 cm long.

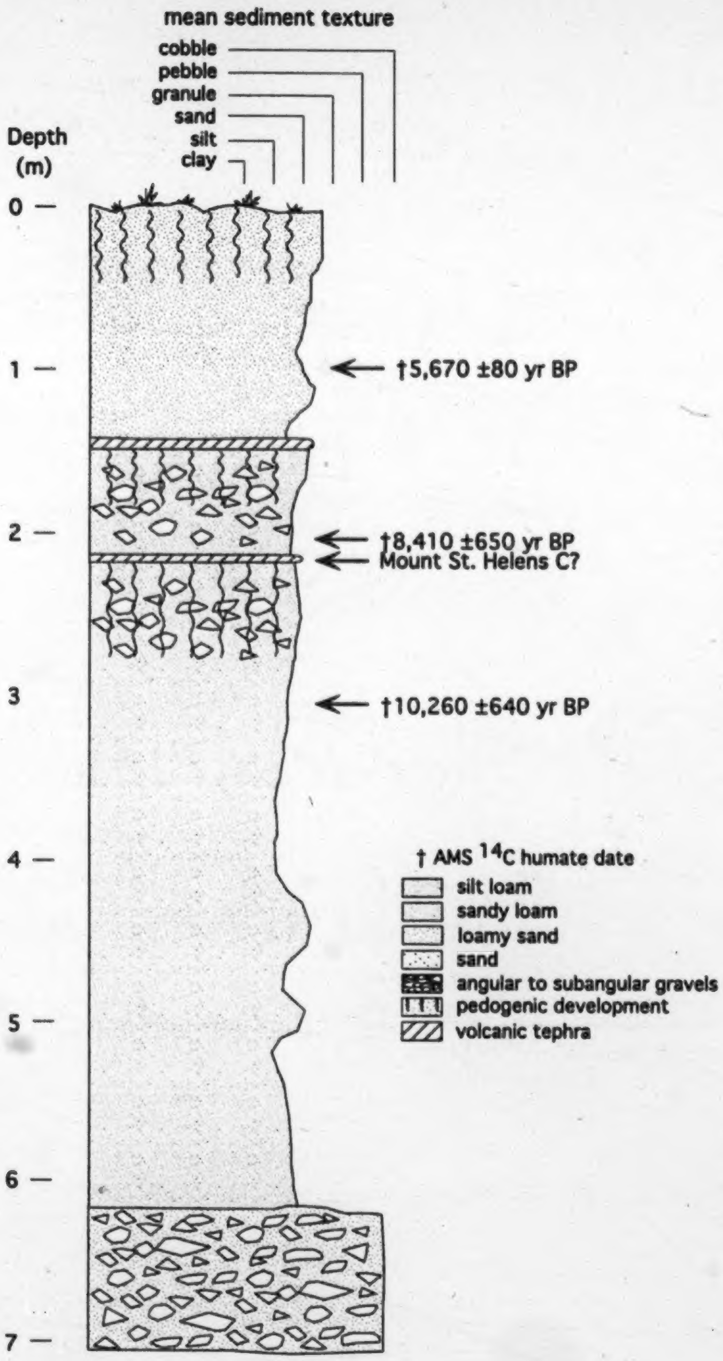
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
4
5
6
7
†5,670 ±80 yr BP
†8,410 ±650 yr BP
Mount St. Helens C?
†10,260 ±640 yr BP
† AMS ¹⁴C humate date
silt loam
sandy loam
loamy sand
sand
angular to subangular gravels
pedogenic development
volcanic tephra

Figure 60. Stratigraphyof SR-35.

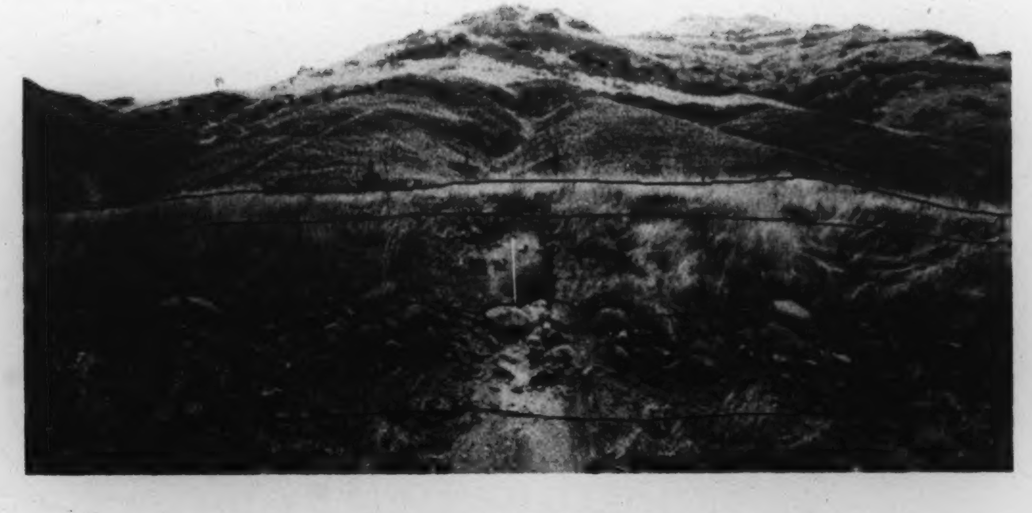

Figure 61. Overview of SR-22 section. Primary deposits of Devils Garden Slide diamict (Qls1) are seen at bottom of profile, overlain by reworked diamict clasts of the Late Pleistocene Alluvium 1 (Qal2). Finer Qal2 sediments cap the rounded diamict gravels and are covered in turn by aeolian deposition of Late Pleistocene Loess 2 (Qae2), which shows a weakly developed paleosol--likely the China Gardens Soil, based on its elevation and stratigraphic position--in its lower reaches. Entire profile is capped by a layer of Holocene Colluvial Gravels (Qcg2). Scale is 2.0 m long.

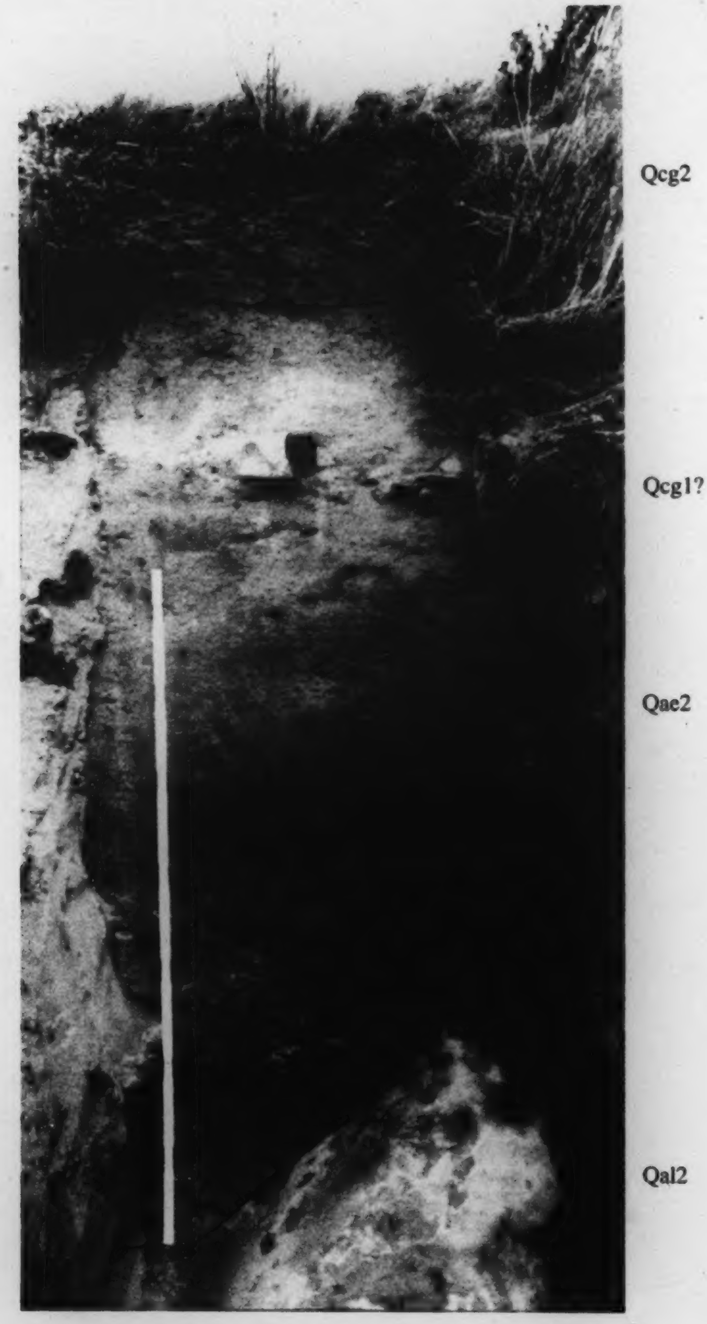
Qcg2
Qcg1?
Qae2
Qal2

Figure 62. Closeup of stratigraphic profile at SR-22. Measuring stick is 1.5 m long.

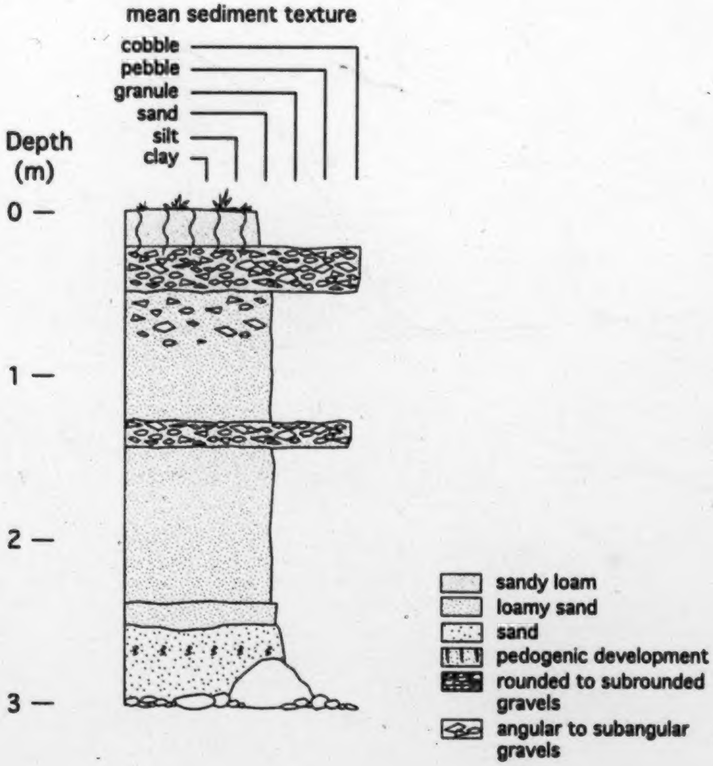
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
sandy loam
loamy sand
sand
pedogenic development
rounded to subrounded gravels
angular to subangular gravels

Figure 63. Stratigraphy of SR-22.

of loess: during arid periods, alluvial overbank deposition provides a source of sediment that is blown upslope into aeolian deposits (Pye 1995).

Age (<25,000 to >15,000 yr BP)

The unit directly overlies a layer of tephra identified as Mount St. Helens set C, which is dated in excess of ca. 35,000 yr BP (Crandell et al. 1981). The position of this tephra at SR-26-4 above a radiocarbon date on soil humate of 25,270 ±530 yr BP (Tx-9137) is suspect, however. It is more likely that the tephra was redeposited at SR-26, which would explain its thickness in the profile (ca. 20 cm) at such a distance from its eruptive source. An AMS date of 11,320 ±90 yr BP (TO-7352) from charcoal recovered on a Rock Creek Soil horizon in the upper portion of SR-26-5 provides a minimum age for Qae2. Other upper limiting ages for Qae2 are provided by humate dates of 14,930 ±1,030 yr BP (TO-7818) and 13,090 ±750 yr BP (TO-7817) on younger Qae3 sediments that overlie what is thought to be a weakly developed China Gardens Soil horizon at SR-23 (see below). Thus, the Qae2 unit is thought to date between ca. >15,000 yr BP and ca. <25,000 yr BP. This temporal context would make the Qae2 temporally associated with Late Wisconsinan-age glacial environments.

Paleosol on the Late Pleistocene Loess 2 -- China Gardens Soil

A paleosol, designated as the China Gardens Soil, is seen in the Late Pleistocene Loess 2 at SR-26-5, beginning at an elevation of 449.47 masl. The China Gardens Soil includes a Bkb horizon with light yellowish brown (10YR6/4) color, silt loam texture, weak subangular blocky structure, common fine calcium carbonate filaments, and a soft dry consistency. This Bkb horizon grades downward into a Btkb horizon with brown (7.5YR5/4) color, a clay loam texture, moderately-developed angular blocky structure, common fine to medium calcium carbonate filaments, and slightly hard dry consistency. Sand-infilled desiccation cracks reach downward from the surface of the China Gardens Soil at SR-26-5, suggesting a change to increased aridity after (or possibly during) the time of pedogenic development. The development of the China Gardens Soil represents a period of surficial stability associated with the end of Qae2 deposition.

Late Pleistocene-Early Holocene Loess (Qae3)

Description

The Late Pleistocene-Early Holocene Loess includes deposits with silt-dominated textures, colors ranging from brown (10YR5/3) to light yellowish brown (10YR6/4), moderate to weak calcium carbonate content, lack of bedding structures, and thin, weakly-developed paleosol horizons.

Distribution

The Late Pleistocene-Early Holocene Loess unit is seen within the T2 and T3 terraces in both the upper and lower portions of the study area. This unit is identified at SR-26-5, SR-42, SR-35, SR-21, 10IH73, and 10IH395 (Figures 64 and 65, see also Figures 24, 25, 31-34, 52, 58, 60). In several sections, the deposition of the Late Pleistocene-Early Holocene Loess unit buried pedogenic development on the Late Pleistocene Loess 2 unit; thus providing a stratigraphic boundary between these two events of loess deposition.

Origin

As with the other loess units in the study area, the texture, degree of sorting, lack of internal bedding, and carbonate content are used to define the Qae3 unit as aeolian in nature. This deposit probably was reworked by wind from alluvial sediments, producing a blanketing loess on landforms adjacent to the river.

Age (>15,000 to >8,400 yr BP)

Radiocarbon dates at SR-23, SR-26-5, and 10IH73 positioned in and above the loess unit suggest an inception before 14,930 ±1,030 yr BP (TO-7818) and a termination of deposition sometime after 10,740 ±220 yr BP (TO-7351), but before 8,410 ±70 yr BP (Beta-114951). An ultimate lower limiting age of Qae3 is provided by the presence of the China Gardens Soil, which is loosely dated between >15,000 yr BP and <25,000 yr BP. Uninterrupted aeolian deposition of the Qae3 unit is dated between 14,930 ±1,030 yr BP (TO-7818) and 13,090 ±750 yr BP (TO-7817) at SR-23 (see Figure 30).

Paleosol on the Late Pleistocene-Early Holocene Loess -- Rock Creek Soil

Paleosol development on the Late Pleistocene-Early Holocene Loess is typified by weakly-developed cambic horizons of light yellowish brown (10YR6/4) to brown (10YR5/3) color with sandy loam

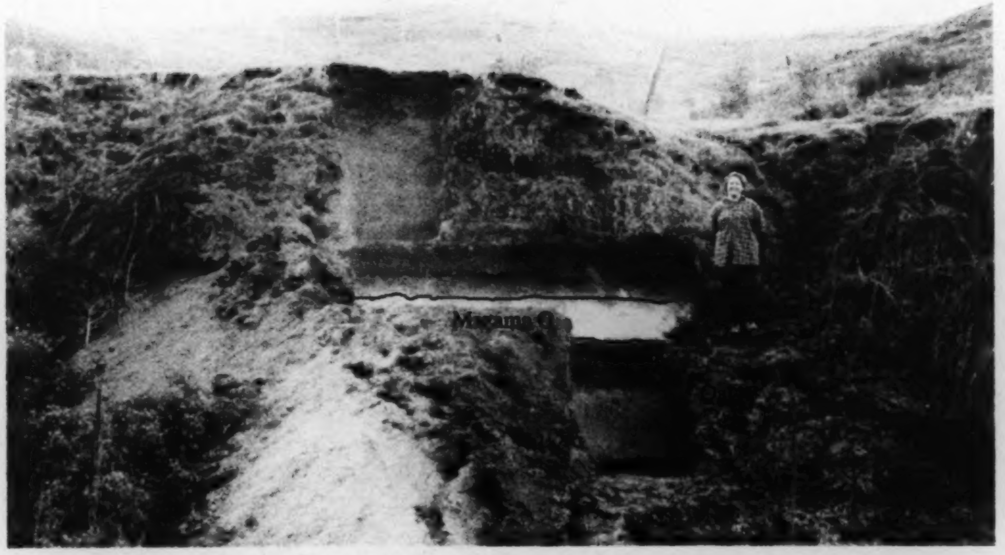

Figure 64. Overview of SR-42 section. Note presence of white tephra layer, identified as Mazama O. Person standing is about 160 cm tall.

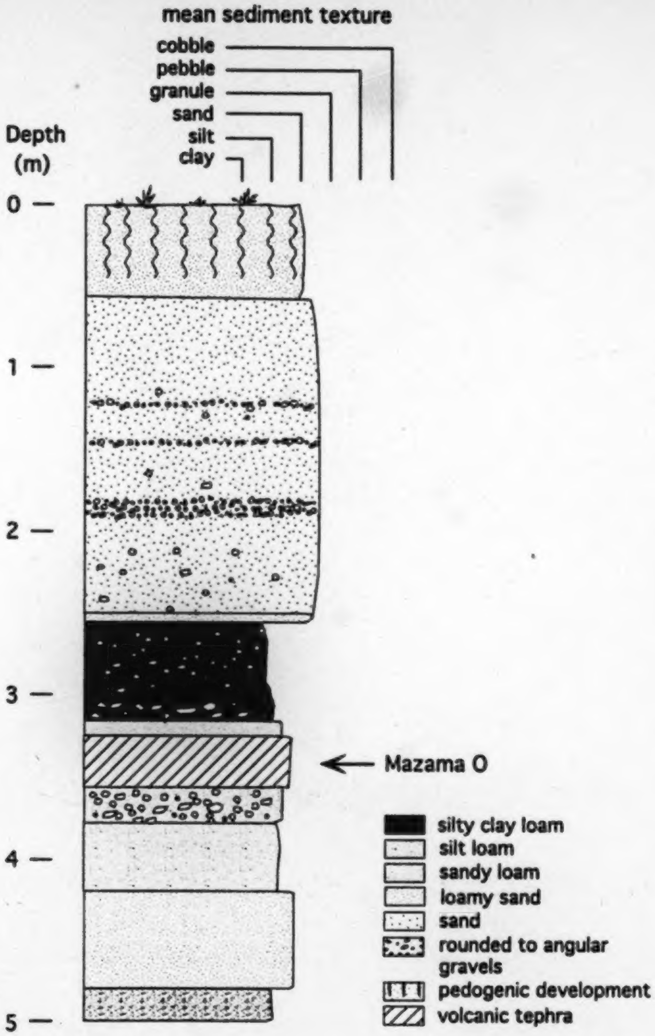
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
Mazama O
silty clay loam
silt loam
sandy loam
loamy sand
sand
rounded to angular gravels
pedogenic development
volcanic tephra

Figure 65. Stratigraphy of SR-42.

to silt loam textures, massive structure, common calcium carbonate mottles and fine filaments, and are typically 30 cm or less in thickness. Pedogenic development on the Qae3 unit is constrained to several discontinuous periods. In several profiles, paleosols are seen as thin horizons separated by unaltered loess. This is characteristic of the Rock Creek Soil and is interpreted as a cycle involving brief periods of surficial stability followed by renewed aeolian sedimentation and soil burial (e.g., SR-26-5 (see Figure 52). Busacca and McDonald (1994:189) observe this pedogenic phenomenon in Palouse loess units of eastern Washington, explaining that, "when and whether soils developed in the loess appears to have been dominantly a function of loess deposition rate because that regulated the time available for soil formation on each volume of the accumulating sediment, and perhaps only secondarily a function of climate or vegetation." Because of this, the temporal span of the Rock Creek Soil is more limited than the Late Pleistocene-Early Holocene Loess; radiocarbon dates at SR-26-5 bracket Rock Creek Soil development between 10,740 yr BP and before 11,320 yr BP. Soil humates from the remnants of a similar pedogenic horizon at SR-27 and SR-23 returned dates of 12,220 ±310 yr BP (TO-7819) and 13,090 ±750 yr BP (TO-7817), respectively. The underlying position of the China Gardens Soil horizon at SR-26-5 provides a lower limiting age of at least 15,000 yr BP. Rock Creek Soil development at 10IH73 ends by ca. 11,370 ±40 yr BP (Beta-114949), marked by a return to aeolian sedimentation at the site. On this basis, the timing of Rock Creek Soil development is placed between ca. 13,000 and 10,740 yr BP.

Middle Holocene Sandy Loess (Qae4)

Description

The Middle Holocene Sandy Loess is found in relatively thick (2 m and more) yellowish brown (10YR5/4) to light yellowish brown (10YR6/4 to 2.5Y6/4) sandy loam deposits. Typically, the Qae4 unit is dominated by fine sand and silt fractions, lacks internal bedding structures, includes common calcite stringers and small concretions, is firm to slightly hard in consitency, and can retain vertical exposures.

Distribution

The Middle Holocene Sandy Loess unit is well-distributed in the upper portion of the study area, seen as blanketing deposits on the T1 and T2 terraces and up onto adjacent slopes. Qae4 units are prominent in the area of the Hammer Creek Recreation Site, particularly between SR-23 and SR-35. The Qae4 unit thins with distance away from the Salmon River, occurring upslope to ca. 30 m (100') above the modern channel. When seen in larger undisturbed profiles, the Middle Holocene Sandy Loess can be identified by its position below the darker-colored Late Holocene Sandy Loess and by its higher calcium carbonate content. Exposures of Qae4 are seen at SR-22, SR-23, SR-27, SR-34, and SR-35 (see Figures 29, 30, 53-56, 58-63).

Origin

The Qae4 unit was probably formed as alluvial sediments deposited in the active floodplain and reworked upslope as aeolian material. The Middle Holocene Sandy Loess is texturally coarser than older loess deposits. This difference is assumed to be linked to changes in middle Holocene alluvial floodplain sediments from glacial to post-glacial environments. As glacial activity in the headwaters of the Salmon River ceased at the close of the Pleistocene or perhaps even the earliest Holocene, glaciogenic input of sediment to the Salmon River likely changed to reflect new sources of sediment production (e.g., slope erosion).

Age (>6,000 to ca. 2,000 yr BP)

An AMS date on soil humates from SR-23 places Qae4 deposition by 6,040 ±620 yr BP (TO-7816), at minimum. In the same section, lower limiting ages of 13,090 ±750 yr BP (TO-7817) and 14,930 ±1030 yr BP (TO-7818) are provided on older Qae3 deposits. Since an erosional unconformity exists between the Qae3 and Qae4 deposits at SR-23, a clear temporal boundary is absent there. Defining a precise minimum age boundary for the Qae4 unit is difficult at this time. The position of a 5,670 ±80 yr BP (TO-7820) AMS date in the middle of the Qae4 deposit at SR-35 shows that deposition continued for some time afterwards. In many sections, a conformable relationship is seen between the Qae4 and Qae5 units. Since the base of the Qae5 unit lies above an archaeological occupation at 10IH1160 dated at 2,320 ±40 yr BP (Beta-135612), and appears to postdate the truncation of the Qal4 alluvium, it is thought that the end of the Qae4 deposition lies near 2,000 yr BP.

Late Holocene Sandy Loess (Qae5)

Description

The Late Holocene Sandy Loess is found as an extensive cover on many landforms adjacent to the Salmon River. The Qae5 unit is coarser that other aeolian deposits, ranging from loamy to loamy sand in texture. Thickness varies from ca. 0.10 m to nearly 1.4 m throughout the study area, based on proximity to sediment source and local strength of winds. The unit is massive in structure and lacks internal bedding.

Distribution

The Late Holocene Sandy loess covers the surfaces of the T1 and T2 terraces, continuing upwards onto adjacent colluvial slopes and bedrock. Qae5 deposits are seen at the Hammer Creek Recreation Site, in the immediate locality of SR-23 and SR-35, downriver at the McCulley Creek site (10IH1160), SR-30, SR-32, and forming a thin cover at the Nipeheme Village site (10IH1312) (Figures 66-69, see also Figures 29, 30, 48, 58, and 60). The unit thins with distance away from the Salmon River, mainly occurring up to 30 m (100') above the modern channel.

Origin

Aeolian reworking of Qal4 sediments is postulated as the source of Qae5 deposits in the study area. The change in texture and color seen in the Late Holocene Sandy Loess from earlier aeolian deposits, is thought to reflect a reworking of the newly-abandoned Qal4 alluvium following a period of major erosion at ca. 2,000 yr BP. This interpretation is consistent with the model of floodplain sediments providing the parent material for aeolian deposits.

Age (2,000 to 0 yr BP)

Radiocarbon dates and artifacts from the McCulley Creek and Nipeheme Village sites suggest Qae5 sedimentation occurred over the last 2,000 yr BP.

Modern Soil Development on the Late Holocene Sandy Loess

Pedogenic alteration of the Qae5 unit is seen throughout the study area. Modern soil development altered Late Holoene Sandy Loess deposits in accordance with local variability in vegetation, relief, and surface stability. A range of soil structures are seen, from moderate to well-developed prismatic columns to massive, weakly-developed soils.

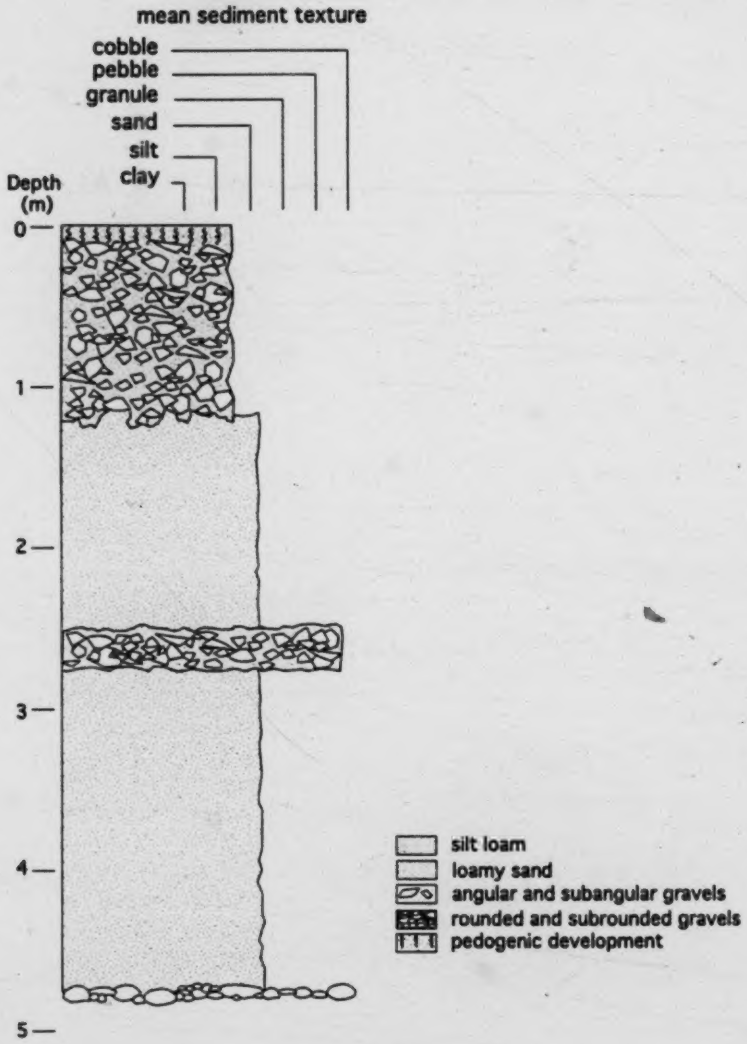
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
5
silt loam
loamy sand
angular and subangular gravels
rounded and subrounded gravels
pedogenic development

Figure 66. Stratigraphy of SR-30.

Figure 67. Photograph of SR-32. Cleaned profile is 3.0 m tall.

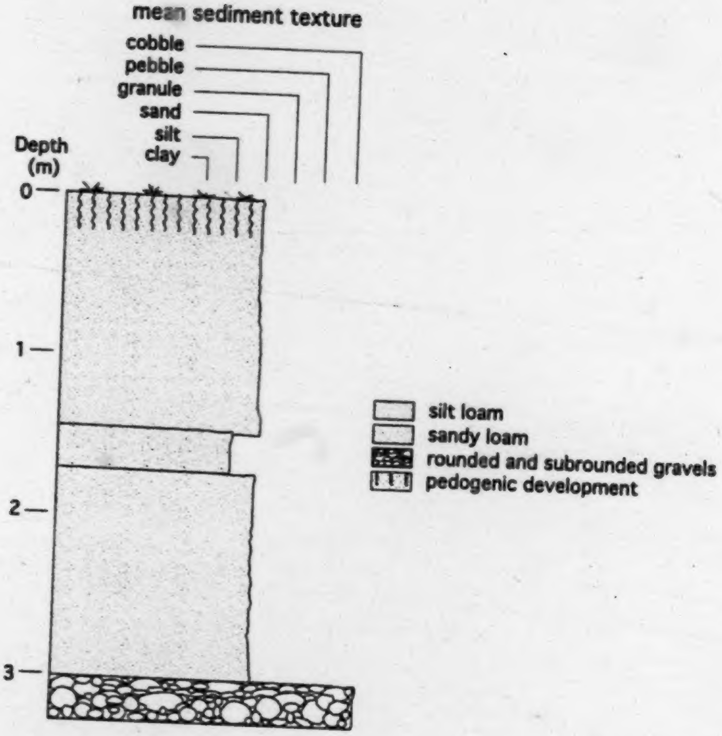
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
3
silt loam
sandy loam
rounded and subrounded gravels
pedogenic development

Figure 68. Stratigraphy of SR-32.

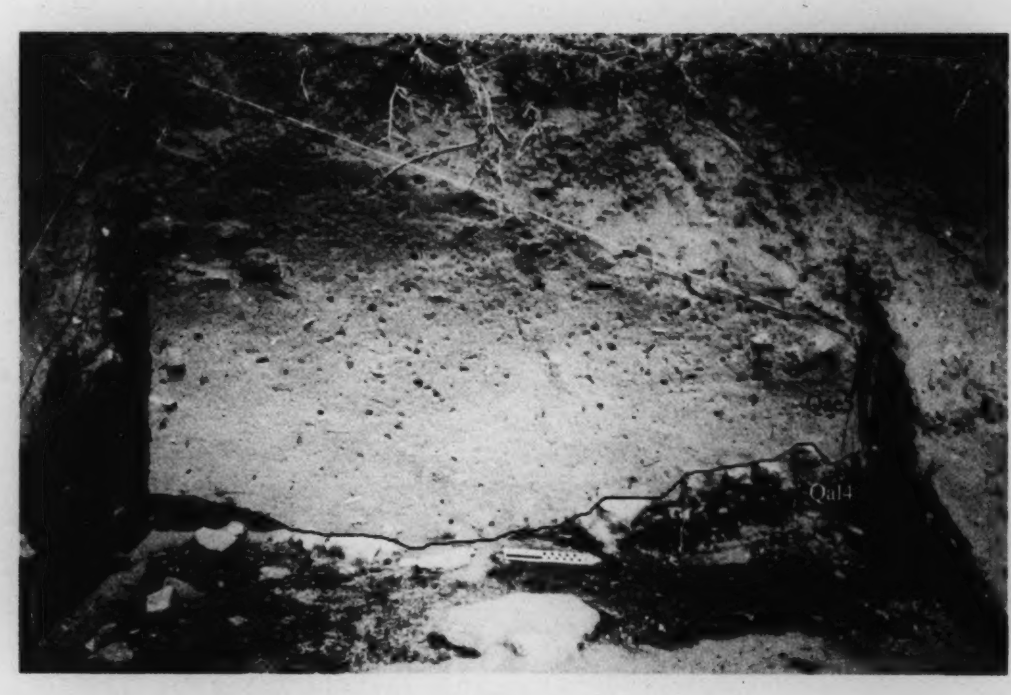

Figure 69. Photograph of 10IH1160 Unit D, west wall. Erosional unconformity separates darker Late Pleistocene-Holocene Alluvium (Qal4) and lighter Late Holocene Sandy Loess (Qae5) deposits. Charcoal at the top of the Qal4 unit returned an AMS age of 2,320 ±90 yr BP, while charcoal from the middle of the aeolian deposit dated to 1,690 ±70 yr BP.

Alluvial Fan and Colluvial Deposition

Alluvial fans form at the mouths of many tributary canyons, containing coarse and fine clastic deposits. Four alluvial fan gravel deposits were identified in the study area; but, all four are never present in the same geomorphic unit. This is likely due to the existence of a close relationship between alluvial channel baselevel and alluvial fan elevation through time. In areas where they are not altered by historic hydraulic placer mining, some alluvial fans extend down to the Salmon River. In other areas, coalescing alluvial fans are apparently truncated by an incising Salmon River. Often, these truncated deposits are themselves incised by their tributary stream, which created a younger, lower alluvial fan that grades to the modern river channel. Internally, the alluvial fans are typically dominated by angular to subangular gravel lithologies that can be traced immediately upslope along tributary canyons. Relict alluvial fans are seen to grade to the surfaces of most terraces. Both of these landforms are often incised, with a modern fan deposit building at a lower elevation, providing evidence of past baselevel adjustment of the Lower Salmon River. Thick (>0.5 meters) deposits of Mazama tephra often occur in alluvial fans, and appear to suggest a pre-6,700 yr BP formation; however, radiocarbon dating suggests that, in many cases, this tephra deposit was reworked after 4,000 yr BP. Alluvial fan deposition aided in the preservation of terrace units in several locations, particularly near canyon walls.

Bedrock weathering generates angular colluvial gravels that accumulate below cliffs and rocky projections. These gravels are commonly seen as talus slopes, present on canyon flanks throughout the study area. In some places, the presence of fine interstitial sediment and/or surficial vegetation helped to stabilize these colluvial deposits; in other areas, bare rock accumulates and slowly works its way downslope under the influence of gravity. Two colluvial deposits are observed in the Lower Salmon River Canyon study area. Chronological control for the formation of these colluvial and alluvial fan deposits is provided by radiocarbon dates and inclusive volcanic tephras (Appendix A and E).

Middle Pleistocene Alluvial Fan Gravels (Qaf1)

Description

Deposits of mixed-lithology, subrounded to subangular pebble to boulder-sized gravel clasts containing in horizontal beds that trend upslope towards tributary canyon mouths are found in limited sections of the study area. Deposits attributed to the Qaf1 unit are recognized by a high degree of weathering and cementation among their gravel clasts.

Distribution

This unit is only seen in the placer mining cuts of SR-40, positioned on the T5 terrace a short distance upstream from the Pine Bar rapids (see Figure 17). The Qaf1 gravels are seen at SR-40 in sections ca. 60 m (ca. 200') above the modern Salmon River.

Origin

Because the Qaf1 gravels are found in continuous beds that dip upslope toward a tributary stream drainage, they are interpreted as having accumulated in the manner of an alluvial fan. A polygenetic origin for Qaf1 coarse clastic material is hypothesized here. The Late Pleistocene Alluvium 2 (Qal2) gravel that accumulated as canyon fill after the Devils Garden Slide is thought to be a possible source of rounded clastic material seen in Qaf1 deposits. Reworking of Qal2 gravels into alluvial fans probably occurred as the Lower Salmon River cut through dam-induced gravel fill. Angular to subangular clastic material seen in Qaf1 deposits is interpreted as originating from tributary canyon erosion and discharge.

Age (~350-400 ka)

A layer of Bend Pumice lies immediately below Qaf1 gravels. This tephra layer originated from central Oregon and was dated between 350 and 400 ka (Sarna-Wojcicki, written communication 1999). Providing a lower bounding age on the deposition of Qaf1 in the study area.

Middle-Late Pleistocene Alluvial Fan Gravels (Qaf2)

Description

Extensive deposits of clast-supported angular to subangular boulder- and pebble-sized gravels are seen to emerge from tributary canyons in a fan-like shape. Texturally, these deposits are dominated by larger clastic sizes (i.e., pebble to boulder), with rare thin beds of fine sediment. The angular nature of the clasts suggests short distance sediment transport, consistent with alluvial fan deposition.

Distribution

These gravels form the base of the T2 terrace in the upper portion of the study area. Exposures are provided along the western edge of the Salmon River between RM 51 and 52. Equivalent deposits may be present in the lower portion of the study area in the lower reaches of Cottonwood Gulch (RM 41), Gill Gulch (RM 42), and in deeper exposures of the McLaughlin feedlot on the northern side of the canyon at RM 40.

Origin

In the area of Cottonwood Gulch and Gill Gulch, Qaf2 deposits are extensive. Active stream channels are incised into the older gravels. The presence of dip-slip block faulting in proximity to Qaf2 deposits suggests that neotectonism possibly influenced the growth of these alluvial fans in some areas. Disequilibrium between tributary canyons and the baselevel of the Salmon River likely resulted as vertical displacement occurred along fault lines. This is expected cause tributary streams to increase their erosive action into bedrock, producing larger deposits of clastic debris than in those tributaries not influenced by faulting.

Age (<350-400 ka to >25,000 yr BP)

The age of Qaf2 deposits is not precisely known. Because landforms bearing Qaf2 deposits are found at lower elevations than Qaf1 deposits, they are considered to be younger than 400 ka. Qaf2 units are positioned higher in elevation, however, than alluvial floodplain deposits that date to the terminal Pleistocene and early Holocene. Therefore, the Middle-Late Pleistocene Alluvial Fan Gravels unit was probably formed sometime after the eruption of the Bend Pumice, but before the deposition of the Late Pleistocene Alluvial Fan Gravels (Qaf3) at ca. 25,000 to 24,000 yr BP.

Late Pleistocene Alluvial Fan Gravels (Qaf3)

Description

Exposures of Late Pleistocene Alluvial Fan Gravels are provided in the upper portion of the study area on landforms affected by historic placer mining. These exposures show thick deposits of clast-supported subangular to angular gravels of cobble to pebble size. Internal bedding is absent as are other indicators of flow direction (e.g., imbrication). Overall, Qaf3 deposits are relatively poorly sorted. The upper and lower boundaries of these gravel deposits dip steeply down to the Salmon River from the mouths of tributary canyons: exposures in the walls of a historic mining adit at Lyons Bar that penetrate into a Qaf3-bearing landform reveal an angle of repose measured between 10° and 12°. Qaf3 units laterally interfinger with aeolian and colluvial deposits with increasing distance away from their originating tributary canyon.

Distribution

All of the Qaf3 deposits were found in the upper portion of the study area, where they are exposed in section at SR-26-4 (see Figures 49 and 52). The gravels are always associated with discrete geomorphic feature that can be clearly identified as alluvial fans from airphotos and field surveys. Late Pleistocene Alluvial Fan Gravels are typically found at elevations of ca. 22 m (ca. 72') above the modern Salmon River on both sides of the canyon.

Origin

Because the Qaf3 unit lacks well-developed paleosol horizons and is notably homogeneous throughout much of its deposit, it is assumed that deposition occurred at a short time scale (perhaps at century scales) with few periods of surficial stability or change in parent material. The Qaf3 unit is found at the mouth of larger tributary drainages, including Owens Gulch (at RM 50.6) and the unnamed drainage above Lyons Bar. Since Qaf3 gravel beds retain slopes that trend in the direction of tributary drainages, are poorly sorted, and are commonly clast-supported, they are interpreted as having originated during alluvial fan deposition.

Age (24,000 to 25,000 yr BP)

Relative ages are provided at SR-26-4 where a Qaf3 deposit overlies the Lyons Bar Soil, which returned a lower limiting age of 25,270 yr BP. An upper limiting age is provided by the presence of the China Gardens Soil, which overlies the Late Pleistocene Alluvial Fan Gravels at SR-26-4. A lower limiting age on the China Gardens Soil is estimated at ca. 24,000 yr BP. On this basis, the Qaf3 unit is relatively dated to a short time period between ca. 24,000 and 25,000 yr BP.

Late Pleistocene-Early Holocene Alluvial Fan Gravels (Qaf4)

Description

Late Pleistocene to early Holocene alluvial fan gravels include angular to subangular pebble- to cobble-sized clasts, typically seen with clast-supported matrix, and interstitial fine sediments that range in color from light yellowish brown (10YR6/4) to brown (10YR5/3). The deposit possesses an anisotropic fabric, lacking evidence of imbrication, and is often found with relatively high slope angles that originate from the mouths of tributary canyon drainages

Distribution

Exposures of Qaf4 gravels are seen at SR-26-5, SR-43, 10IH395 and 10IH1160 (Figures 70 and 71, see also Figures 28, 31, 32, 39, 40). Deposits are not typically found at the surface, but encountered in placer mining cuts in the T1 terrace, where they are deeply buried. The Qaf4 unit is thin compared to other alluvial fan gravel deposits, measuring between tens of centimeters and up to 2 m in thickness. The gravels are found within large alluvial fans, identified on the basis of their characteristic surficial geometry and position at the mouth of larger tributary stream canyons.

Origin

The presence of a poorly sorted, commonly clast-supported matrix within relatively high-angle continuous beds, intercalated with sandy or silty beds, that trend toward tributary drainages suggests that the Qaf4 unit originated in an alluvial fan depositional environment. Because the Qaf4 gravels originate from bedrock erosion in tributary drainages, the lithology of the deposits may differ throughout the study area.

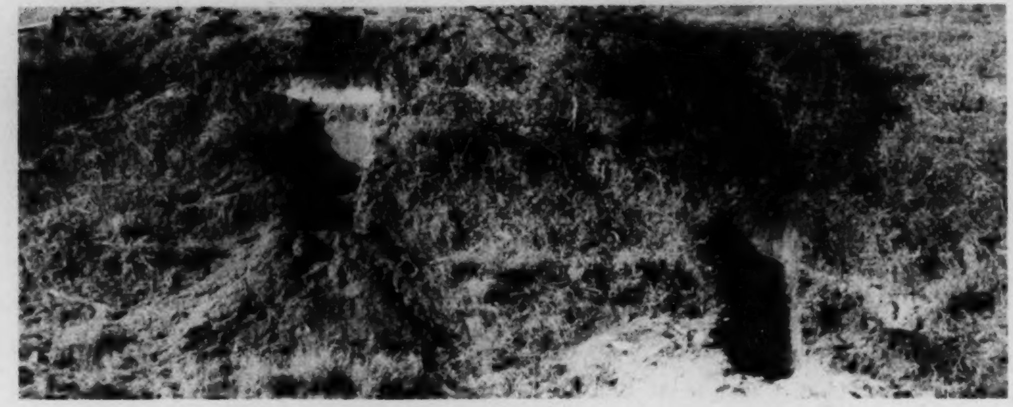

Figure 70. Overview of SR-43 section.

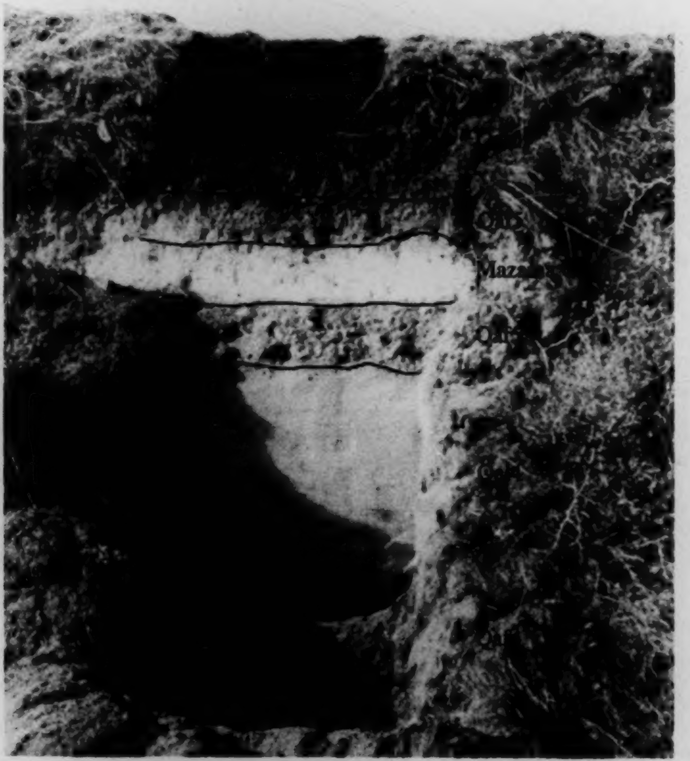

Figure 71. Upper portion of SR-43 stratigraphy. Light colored tephra is Mazama O.

Age (10,700 to 8,500 yr BP)

At SR-26-5, Qaf4 deposits overlie Rock Creek Soils developed in Qae3 loess, which are associated with two AMS dates on charcoal of 10,740 ±220 yr BP (TO-7351) and 11,310 ±80 yr BP (TO-7352). At SR-35, a Qaf4 deposit is closely bracketed between soil humate AMS dates of 10,260 ±640 yr BP (TO-7822) and 8,410 ±650 yr BP (TO-7821). On this basis, a Late Pleistocene-Early Holocene age is provided for Qaf4 units.

Middle Holocene Alluvial Fan Gravels (Qaf5)

Description

Sediments of the Qaf5 unit tend to vary in appearance more than other alluvial fan deposits. Middle Holocene Alluvial Fan Gravels can appear as deposits of subangular to angular cobbles and pebbles in a silty or loamy sand matrix-supported context with relatively high calcium carbonate context, or as intercalated deposits of angular to subangular clast-supported calcareous cobble and pebble gravels, and sandy sediments. In many cases, alluvial fan gravels interfinger with alluvial floodplain sediments at their distal margins.

Distribution

Exposures of Middle Holocene Alluvial Fan Gravels are seen at 10IH395, and in SR-35 and 10IH1160 in the upper portion of the study area, below 1600'(488 m) elevation (see Figures 31, 32, 40, 59, 60).

Origin

Qaf5 deposits are found in poorly sorted, commonly clast-supported matrix within relatively high-angle continuous beds, often seen intercalated with sandy or silty beds, that trend toward tributary drainages, suggesting an origin in an alluvial fan depositional environment.

Age (ca. 8,500 to 7,000 yr BP)

At SR-35, Qaf5 deposits are bracketed between soil humate AMS dates of 8,410 ±650 yr BP (TO-7821) and 5,670 ±80 yr BP (TO-7820); however, the younger of the two lies ca. 25 cm above the surface of the Qaf5 unit. Pedogenic development of what is interpreted as the American Bar Soil (dated between 6,000 and ca. 7,000 yr BP) into the Qaf5 deposit at SR-35 helps to narrow down the age boundaries even further.

Paleosol on the Middle Holocene Alluvial Fan Gravels -- American Bar Soil

A well-developed pedogenic horizon developed on a poorly sorted Qaf5 matrix-supported cobbly sandy loam deposit is seen at SR-35. Dated to the middle Holocene, this soil differs from other American Bar Soil exposures, as it contains a grayish petrocalcic horizon. This increased development of pedogenic carbonate is thought to be the result of previously-higher rates of alluvial runoff on alluvial fan deposits at SR-35. Although there is no stream activity in the immediate area of SR-35, it is clear that alluvial deposition in a fan context occurred in the past. The discontinuation of alluvial deposition may be related to local faulting, which possibly diverted drainage of the unnamed creek that currently flows into Hammer Creek at an elevation of 536.5 masl (1760' asl). Following the burial of the American Bar Soil at SR-35, conditions favoring the development of petrocalcic features cease, followed by a change to aeolian deposition, providing additional evidence for the stream piracy event.

Late Holocene Alluvial Fan Gravels (Qaf6)

Description

Late Holocene Alluvial Fan Gravels are best differentiated from other alluvial fan deposits on the basis of their color, texture, geomorphic association and stratigraphic position. Modern soil development on the Qaf6 unit gives the deposit a darker color than other alluvial fan units, ranging from very dark grayish brown (10YR3/2) to brown (10YR4/3). The unit is nearly always found to overlie Mazama tephra.

Distribution

Gravels attributed to the Qaf6 unit were found in many localities, SR-21, SR-22, SR-30, SR-42, SR-43, 10IH395, 10IH1160, and 10IH1308 (Figures 72-75, see also Figures 24, 25, 28, 32, 39, 64-66) Qaf6 gravels are typically located near the mouth of tributary canyons up to an elevation of 37 m (120') above the modern Salmon River channel.

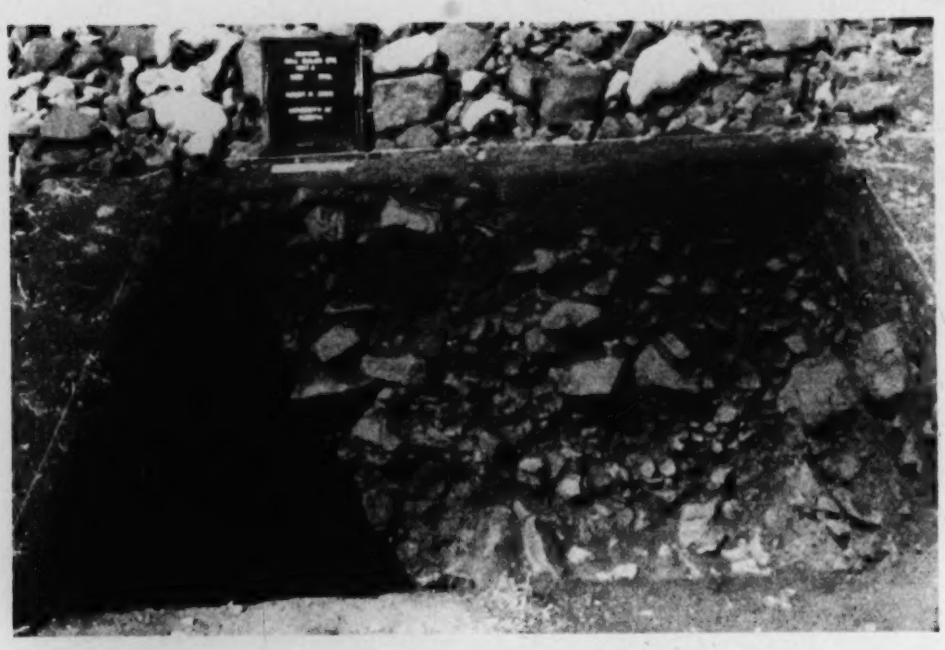

Figure 72. Photograph of 10IH1308 Unit A, west wall, showing Late Holocene Alluvial Fan Gravels (Qaf6) overlain by Late Holocene Sandy Loess (Qae5). Pit is 2.0 m across top.

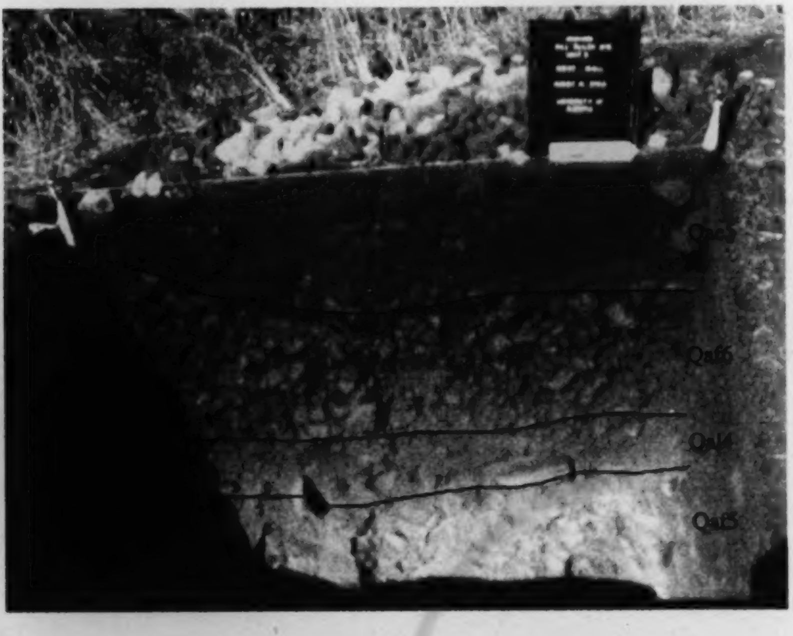

Figure 73. Photograph of 10IH1308 Unit D, west wall. Late Holocene Sandy Loess (Qae5) caps Late Holocene Alluvial Fan Gravels (Qaf6), which overlie Late Pleistocene-Holocene Alluvium (Qal4) and Middle Holocene Alluvial Fan Gravels (Qaf5). Pit is 2.0 m across at top.

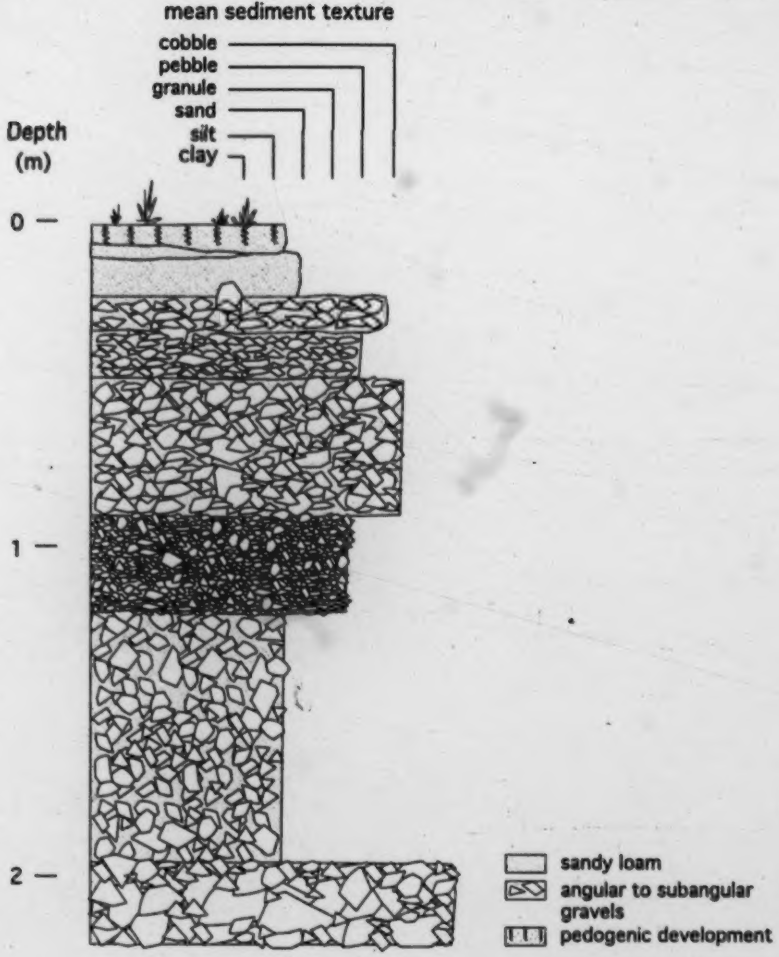
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
sandy loam
angular to subangular gravels
pedogenic development

Figure 74. Stratigraphy of 10IH1308 Unit A.

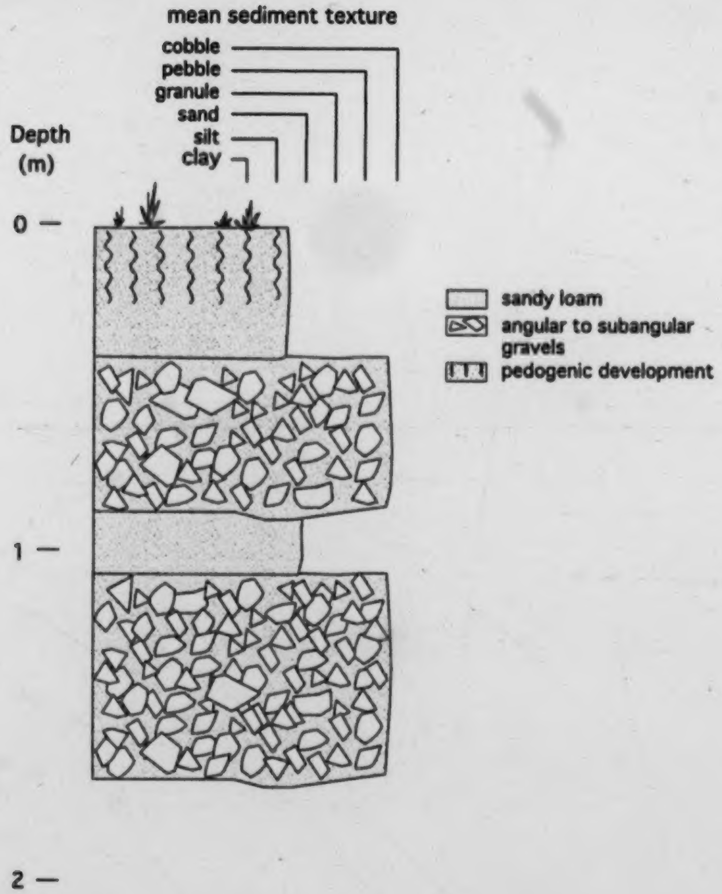
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth
(m)
0
1
2
sandy loam
angular to subangular gravels
pedogenic development

Figure 75. Stratigraphy of 10IH1308 Unit D.

Origin

The Qaf6 unit shares many similarities with other alluvial fan gravels, including steepened continuous beds of poorly sorted gravels and loamy sediments, often clast-supported, which emerge from the mouth of tributary drainages throughout the study area. Deposition of Qaf6 sediments was observed by the author during periods of extended spring season precipitation or following a short-duration, high-intensity summer thunderstorm. In both cases, alluvial fan deposits can accumulate rapidly, burying roads under 50 cm or more of matrix in an hour or less.

Age (5,000 to 0 yr BP)

Late Holocene Alluvial Fan Gravels are associated with many radiocarbon dates in the study area. Radiocarbon samples recovered from Qaf6 deposits fall between 4,940 ±60 yr BP (Tx-9275) and 1,140 ±60 yr BP (TO-7350); however, 20th century alluvial fan activity on Qaf6-bearing landforms suggests that Late Holocene Alluvial Fan Gravels continue to be deposited. This places Qaf6 deposition between ca. 5,000 yr BP and 0 yr BP.

Older Colluvial Gravels (Qcg1)

Description

Colluvial gravels blanket most slopes in the study area, retaining relatively high angles of repose (e.g., 34°). Two general colluvial gravel units can be defined on the basis of their inclusive fine sediment matrix. The Older Colluvial Gravels are clast-supported, with at least 65% of the sediment of pebble or greater size. The finer interstitial matrix is dominated by silt-sized sediments that typically impart a light yellowish brown (10YR6/4) color to the unit.

Distribution

This unit is seen in profile at 10IH395, SR-44, and in road cuts throughout the study area (Figure 76, see also Figure 14). Qcg1 deposits are typically positioned beneath the Holocene Colluvial Gravels in a vertical stratigraphic sequence. In parts of the canyon, Older Colluvial Gravels appear at the surface, appearing as an exhumed remnant.

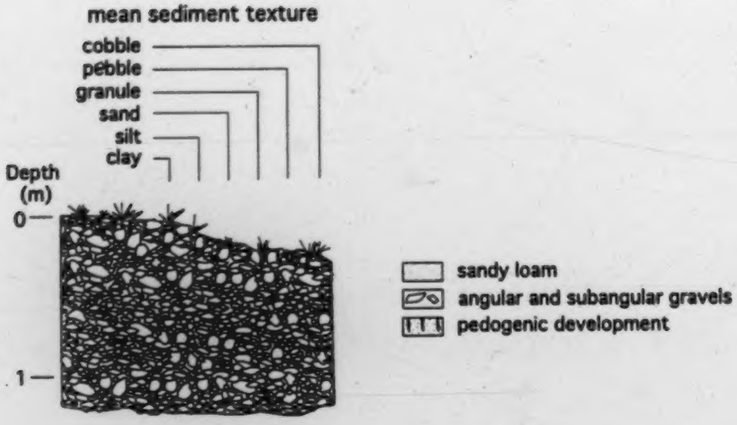
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
sandy loam
angular and subangular gravels
pedogenic development

Figure 76. Stratigraphy of SR-44.

Origin

The origin of the Qcg1 unit is likely polygenetic. As colluvial gravels accumulated on canyon slopes, loess deposition would have added a fine sediment component. As the two depostional processes continued, loess infiltrating the clast-supported matrix of the Qcg1 unit would help to lock the gravels in place.

Age (>4,500 yr BP)

The age of the Older Colluvial Gravels is established indirectly, by its incorporation of light yellowish brown loess and its stratigraphic position below the Holocene Colluvial Gravels. The lighter-colored loess that is seen as interstitial matrix in the Qcg1 unit is only found in deposits dating to the middle Holocene and older. At 10IH395, Qal4 deposits laterally grade into Qcg1 deposits, showing a synchronic facies relationship dating to the middle Holocene. The age of the Qcg1 unit is thought to extend back into the Pleistocene Epoch, however, although direct chronometric dating is not available to support this.

Holocene Colluvial Gravels (Qcg2)

Description

The Holocene Colluvial Gravels are similar to the Older Colluvial Gravels, comprised of a clast-supported framework of angular to subangular pebble to cobble gravels with a fine interstitial sediment. The two deposits can be differentiated on the basis of the fine sediment component. The fine sediments associated with the Qcg2 unit are darker in color, typically brown (10YR4/3) to very dark grayish brown (10YR3/2). While this difference is clearly caused, at least in part, by late Holocene pedogenic alteration, distinct textural changes are seen in the Qcg2 unit. The finer sediments associated with Holocene Colluvial Gravels retain a higher percentage of clay than does the Qcg1 unit. During the spring, when the upper portion of slope sediments are often saturated, the darker Holocene Colluvial Gravels are observed to slump and creep more frequently than deposits of Qcg1 exposed at the slope surface. Thus, modern soil forming and seasonal slope processes produced different weathering rates on the Qcg2 unit.

Distribution

Holocene Colluvial gravels are widespread in the study area and are always seen positioned above the Older Colluvial Gravels in undisturbed stratigraphic sections such as SR-44, where they often retain slope angles in excess of 34° (see Figure 14, 76).

Origin

As hypothesized for the Older Colluvial Gravels, the Qcg2 unit was probably formed under polygenetic circumstances. In this case, however, a greater portion of the finer sediment may be introducted into the gravel framework through slopewash and gravity-induced surficial flow. This appears to represent a change from aeolian sediment input to colluvial/alluvial sediment deposition. The source of finer sediment in Holocene Colluvial Gravels may be traced to the decomposition of local canyon bedrock under a more humid weathering regime than seen during the formation of the Older Colluvial Gravels.

Age (4,500 to 0 yr BP)

At the American Bar site (10IH395), Holocene Colluvial Gravels immediately overlie Mazama tephra, which, in turn, rests upon Qal4 deposits associated with a soil humate date of 6,070 yr BP. The construction of a semi-subterranean pithouse foundation into Qcg2 deposits dates to 1,370 ±40 yr BP at 10IH395, pointing to a continuation of colluvial development into the late Holocene. At the Rock Creek Bridge Site (10IH2491), accumuation of Qcg2 deposits appears to coincide with a shift in Rock Creek channel baselevel after 2,000 yr BP. The fine sediment component of the Qcg2 unit retains many qualities that are similar to the style of pedogenic weathering seen in the Hammer Creek Soil, which likely developed during the latter half of the Holocene. Therefore, the Holocene Colluvial Gravels are expected to date between ca. 4,500 yr BP and 0 yr BP.

Late Quaternary Geology of the Study Area: Summary and Discussion

A summary diagram showing the chronology and relations of depositional facies, pedostratigraphic units and allostratigraphic units is provided in Table 3. The following discussion will address specific aspects of LSRC late Quaternary geology during different time periods.

Middle Pleistocene

Very little surficial geology is preserved in the canyon dating to the Middle Pleistocene. The limited deposits preserved in the T5 terrace in the lower portion of the study area suggest that the middle Pleistocene river channel was at least 70 m (230') higher than the position of the modern channel at Pine Bar rapids. The sequence of deposits in the stratigraphic exposure at SR-40 are interpreted to represent alluvial overbank deposition over alluvial channel gravels, with alluvial fan deposits seen to interfinger with alluvial overbank deposits.

Late Pleistocene

The Late Pleistocene is better represented in the stratigraphy of the study area. As seen in many stratigraphic localities, this period marked a major change in the geologic history of the canyon.

Devils Garden Slide and Fluvial Readjustment

The Devils Garden slide, and the subsequent distribution of slide diamict in the area of Rock Creek, undoubtedly affected the fluvial geomorphology and sedimentological behavior of the Salmon River in the study area (and theoretically to points upriver and downriver) until the late Holocene. Slide diamict can be traced to the 500 masl (1640' asl) contour line. Assuming a pre-slide channel elevation of ca. 427 masl (1400' asl), on the basis of the elevation of earlier alluvial deposits in the upper portion of the study area, the canyon area in the immediate vicinity of the Rock Creek-Salmon River confluence would be filled with about 73 m (240') of slide diamict. With an interlocking boulder and fine sediment diamict rapidly emplaced in the canyon bottom, the Salmon River would likely be impounded for some time. At

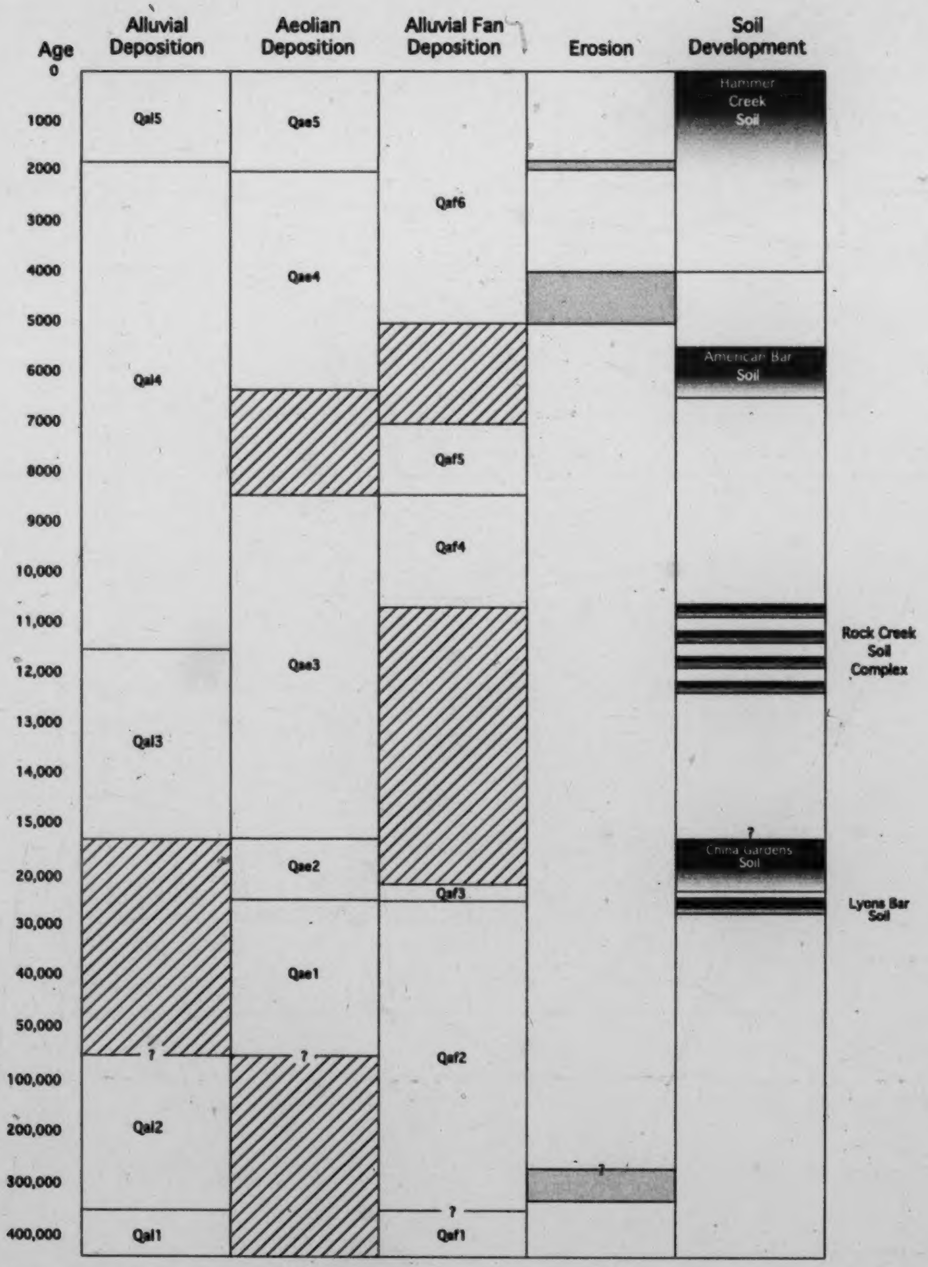

Table 3. Chronological summary of depositional facies, pedostratigraphic units, and allostratigraphic units in the study area. Hatched boxes represent periods with no observed deposits.

minimum, the surface of a pool might lie at ca. 488 masl (1600') behind the slide diamict, which currently crosses the river just above Lucile at RM 77.5.

Large-scale channel aggradation probably occurred in the Lower Salmon River Canyon as the alluvial load was unable to move downstream beyond the Devils Garden Slide dam (Leopold et al. 1964; Schumm 1969). The effects of a lowered channel gradient undoubtedly propagated upriver beyond the pool itself, causing alluvial sediments to be deposited in a thick canyon fill in an effort to steepen the gradient of the channel. By increasing the channel gradient, the Lower Salmon River could derive energy for clastic transport from gravity. In time, when the base of the channel reached the top of the slide diamict, and its upriver portion attained a gradient that provided sufficient discharge, the depositional mode of the Salmon River would shift to an erosional regime, with work directed towards the removal of the canyon fill and the establishment of a different channel gradient. The presence of extensive gravel deposits in many bars upriver of the study area provide witness to this hypothesized process of canyon filling. These deposits were left behind after the Salmon River cut through the Devils Garden slide dam and downward towards its modern channel position.

It is unclear how long the Devils Garden Slide dam impounded the Salmon River to a level of 488 masl (1600' asl). Equally as uncertain is the rapidity of canyon fill reworking once the dam was breached. As the river reworked the diamict dam, the larger clastic component was apparently lagged in many areas, forming a coarse, thick channel fill, which appears as Late Pleistocene Alluvium (Qal2) deposits in the study area. Large well rounded to subrounded basalt boulders are present in exposures along the downstream edge of Cooper Bar (SR-19, SR-20, and on the surface of Pine Bar (RM 42.5)). Erratic boulders are also seen on the surface of the point bar immediately below the mouth of Rice Creek, where the Salmon makes a sharp westward turn just above RM 37. Several terraces in the area of Cooper Bar were formed following the fluvial erosion of the Devils Garden slide diamict, although the exact timing of this event is unclear. The slide diamict retains angular to subangular shapes at its upper elevational limits, having escaped the erosional forces of the Salmon River.

By ca. 12,000 yr BP, the Salmon River apparently reworked the slide diamict to a great degree, with the position of the river channel perhaps 6m (20') above its modern position at the mouth of Rock

Creek. From this baselevel, the Salmon River deposited alluvium immediately before 11,310 ±80 yr BP (TO-7358) at SR-21, marking the first evidence of a new kind of of floodplain growth that would continue until the late Holocene.

Loess Deposition and Surficial Stability

Most of the geologic units dating to this time are aeolian in origin, suggesting the presence of arid conditions. Late Pleistocene loess deposits are abundant in the study area. The earliest loess deposits date just after ca. 60,000 yr BP, and are intermittently deposited in the canyon until after ca. 10,740 ±220 yr BP (TO-7351). The timing of loess deposition in the Lower Salmon River Canyon study area suggests formation during periods when large amounts of sediment were available for transport by prevailing winds and are not necessarily directly correlated to glacial activity. This situation is also advanced to explain Palouse loess formation (Busacca and McDonald 1994:188-189), with aeolian processes reworking floodplain silts following catastrophic flooding events. Although seen at a much smaller scale in the Lower Salmon River Canyon, and not linked to catastrophic glacial lake flood events, loess deposition appears to follow the same pattern of aeolian redeposition of floodplain sediments seen in the Palouse region.

Late Pleistocene to Early Holocene

Floodplain development is sporadic between ca. 11,400 yr BP and 8,500 yr BP, and may be explained in different ways. Instability in depositional systems, showing rapid changes from alluvial to aeolian, suggest that geomorphic systems were responding to the influence of fluctuating climatic forces. Deposition of silty floodplain deposits at SR-21 dates immediately before 11,310 ±80 yr BP (TO-7358), whereas across the river at the Cooper's Ferry site (10IH73), pedogenic development appears to begin before 11,370 ±40 yr BP (Beta-114949), closely coinciding with these apparently mesic conditions. After 11,370 yr BP, a change in deposition to the Qae3 loess at 10IH73 marks a shift to drier, windier conditions. This return to aeolian conditions is matched by an abrupt change to aeolian sand deposition at SR-21, which rapidly buried the 11,310 yr BP alluvial floodplain sediments. By ca. 9,000 yr BP, alluvial deposition resumes in the area of the Cooper's Ferry, Bug Slope, American Bar, McCulley Creek sites, reflecting the more stable development of an extensive floodplain in the the study area.

Alternatively, changes in the character of alluviation may enhance or limit the availability of sediment to be transported by aeolian process. Fluctuations in sedimentation between 11,400 to 8,500 yr BP could also be attributed to changes in the geomorphic behavior of Lower Salmon River and not necessarily linked to climate. For example, varying sediment inputs to the alluvial basin could cause the river to alternate between meandering and braided channel systems. Under a braided channel system, more sediment would be available for aeolian erosion and transport; whereas a meandering stream system might expose less sediment to be worked upslope. The result of these changes in river channel form could produce effects in alluvial and aeolian sedimentation records, which, in the absence of other proxy datasets, could be confounded as climatically-forced depositional periods.

Middle Holocene

Between the American Bar site (10IH395) (RM 36.9) and the Rock Creek Bridge site (10IH2491) (RM 38.9) floodplain aggradation continued during the middle Holocene period. Extensive deposits of Qal4 alluvium are seen at Bug Slope (10IH1220) (RM 37.6) in thickness of ca. 2 m or more. Qal4 deposits thin upriver and downriver from Bug Slope, with deposits ca. 1.4 m thick at the Rock Creek Bridge site (10IH2491) and ca. 0.9 m at the American Bar site (10IH395). Further upriver, Qal4 alluvium was located at the McCulley Creek site (10IH1160) (RM 48.9) and at the Hammer Creek Recreation Site, in sections SR-42 and SR-43 (RM 52.3). At McCulley Creek, the thickness of the Qal4 unit is estimated at ca. 0.8 m. Between SR-42 and SR-43, two distinct periods of Qal4 deposition are visible, separated by a layer of grayish brown (10YR5/2) very fine sand. The Qal4 units in the Hammer Creek area show a lower degree of sorting than their counterparts seen downriver, suggesting a reduction in Qal4 depositional energy with distance downstream from this point. Tributary canyons appear to be accumulating colluvial and alluvial fan material during this time. Rocky Canyon, the largest tributary canyon in the study area, shows extensive colluvial aggradation during the middle Holocene, as reflected in the presence of Older Colluvium deposits and Mazama tephra.

Late Holocene

Alluvial downcutting occured along the main and tributary channels immediately after 2,000 yr BP, forming the T1 terrace. In the area of Bug Slope, the Qal4 floodplain surface is nearly 24 m (80') above the position of the modern Salmon River channel. Twenty-four kilometers (15 miles) upriver, the surface of the T2 terrace at the Hammer Creek Recreation Site is roughly 9 m (30') higher than the modern channel. This difference in downcutting is directly related to the thickness of slide diamict in the lower portion of the study area. In the lower portion of the study area, this erosional episode had a dramatic effect on the structure of the floodplain. At its maximum extent, the Qal4 floodplain is estimated as being roughly 244 m (800') wide in the area of Bug Slope. Today, the width of the floodplain in this area is less than 15 m (50'). The difference represents an estimated 94% reduction in floodplain size following the post-2,000 yr BP erosional event. This undoubtedly had a dramatic effect on the structure of riparian ecosystems in the study area.

Following erosion after 2,000 yr BP, alluviation began anew, leading to the formation of the modern floodplain (T0). Backhoe trenches at the Hammer Creek Recreation site (e.g., HC-2) revealed a record of fining-upwards overbank deposition (Qal5). Wood charcoal recovered at 93 cm below the surface of HC-2 returned an AMS date of 1,770 ±110 yr BP (TO-7812), providing a late Holocene age for the construction of the T0 landform. Undisturbed archaeological components associated with the T0 floodplain are all late Holocene in age, further supporting a post-2,000 yr BP age for this final stage of alluviation (David Sisson, personal communication 1999).

Problems of Stratigraphic and Chronological Resolution

Tephrochronology

Volcanic tephras provide useful chronostratigraphic markers in Quaternary stratigraphic studies in contexts where their temporal integrity is not compromised by secondary redeposition following initial airfall. None of the five tephra layers encountered in the study area are considered to be in a primary airfall position. Many of the problems associated with using a tephrochronology in the study area can be traced to the pronouced vertical relief of canyon settings and the operation of key geomorphic agents in the Salmon

River Canyon. Following its eruption, volcanic tephra will initially cover low angle portions of landscape in a relatively even blanket, with differential thicknesses caused by vegetation cover. Immediately after the airfall event, geomorphic processes work to erode, transport and redeposit tephra throughout the landscape. In time, undisturbed portions of the original airfall that remain may become incorporated into the stratigraphic record as they are buried by new sediments. Future erosion of tephra-bearing landforms will diminish the total amount of undisturbed tephra deposits in the landscape, whereas continued deposition or surficial stability will help to preserve tephra layers.

The Lower Salmon River Canyon's high-relief topography coupled with low vegetation cover on its slopes provides little opportunity for primary airfall tephra layers to become incorported into the local stratigraphic record. Tephras that are deposited on floodplains or on the lower slopes adjacent to the riparian zone are either eroded and washed downstream or blown upslope where they become dispersed into other aeolian deposits, and are no longer seen as discrete layers. Alluvial fans are the best places to find volcanic tephras in the study area, where they are almost always seen in thick, redeposited layers. A good example is seen at the mouth of Shorty Canyon (RM 49.4) where a large plug of Mazama set O tephra rests on the surface of the alluvial fan (Figure 77). The primary airfall layer of Mazama set O layer produced during the 6,700 yr BP (Bacon 1983; Fryxell 1965) eruption of modern-day Crater Lake in Oregon should occur in thicknesses of 30 cm or less in the Lower Salmon River Canyon (Matz 1991:41).

While overthickened tephra deposits are immediately suspected as being redeposited, thin tephra layers cannot be assumed to represent primary airfall. In several cases, radiocarbon dates reveal redeposited tephra layers in the study area. At the Rock Creek Bridge site (10IH2491), a discontinuous layer of Mazama O tephra was identified and bracketed between radiocarbon dates of 1,960 ±40 yr BP (Beta-114808) and 2,010 ±40 yr BP (Beta-114805). At the American Bar site (10IH395), Mazama O tephra unconformably overlies an eroded paleosol that produced a soil humate date of 6,070 ±60 (Tx-9138). At the Bug Slope site (10IH1220), wood charcoal found at the lower boundary of alluvium immediately overlying Mazama O tephra was dated at 3,070 ±50 yr BP (TO-7353). Thus, it appears that Mazama O tephra is best considered a temporal marker of Lower Salmon River Canyon erosion and redeposition between ca. 6,000 and 2,000 yr BP.

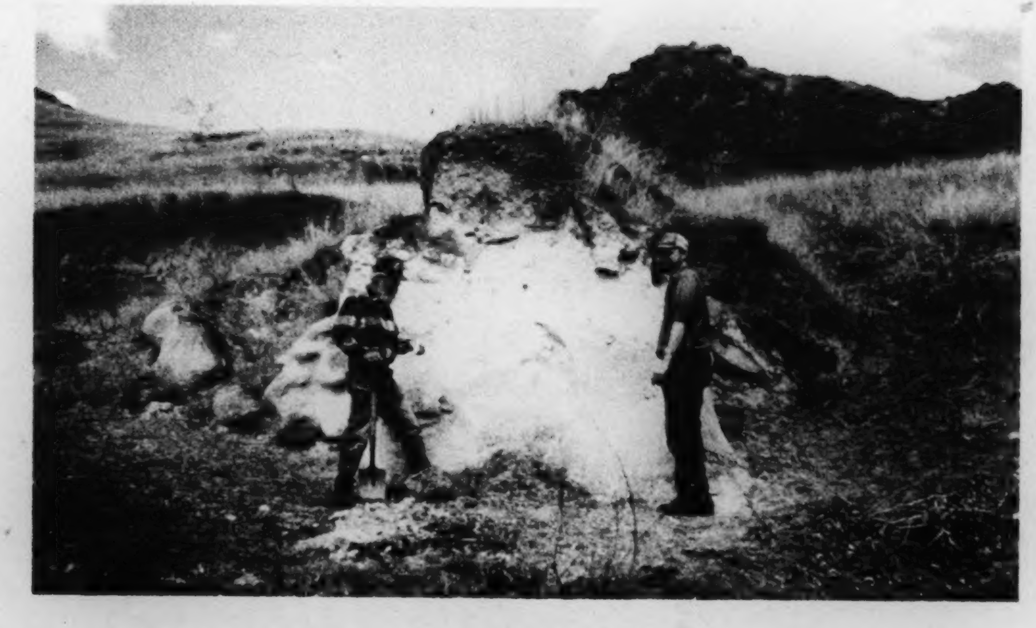

Figure 77. Overthickened deposit of Mazama O tephra on surface of alluvial fan at the mouth of Shorty Canyon (RM 49.5). Men are about 182 cm tall.

Redeposition is not confined to the Mazama O tephra, however. At SR-26-5, a tephra best matched to Glacier Peak set G, which was dated to 12,750 ±350 yr BP (Porter 1978), overlies a set of paleosols associated with AMS dates on charcoal of 10,740 ±220 yr BP (TO-7351) and 11,320 ±40 yr BP (TO-7352). Deeper in the SR-26-4 section, a layer identifed as one of the Mount St. Helens set C tephras, which date between 36,000 and 37,600 yr BP (Mullineaux 1986), overlies a 25,270 ±530 yr BP (Tx-9137) conventional ^{14}C date on soil humate. This information suggests that all tephra layers encountered in the Lower Salmon River Canyon must be considered as redeposited unless shown otherwise. While this reduces the usefulness of tephras as temporal markers in the study area, additional dating of the redeposition events themselves may help to clarify the timing of local episodes of erosion and redeposition.

Timing and Magnitude of Erosion in the Study Area

Several erosional events are identified in Lower Salmon River Canyon stratigraphic records. This erosion is marked by the truncation of soil surfaces or bedded deposits, producing a disjunct boundary between geologic units. The majority of erosional episodes in the study area are the result of alluvial action. Lateral and vertical erosion of stream and river channels remove large amounts of sediment. One such period of erosion occurred at the American Bar site just after 6,000 yr BP. A soil horizon developed into Qal4 floodplain sediments was truncated by the development of a small gully by a tributary stream (Figures 78 and 79). Just upriver, stratigraphic exposure at the Bug Slope site shows convoluted boundaries between alluvial floodplain deposits and Mazama O tephra. The surface of the floodplain apparently was eroded prior to the deposition of the tephra, which was in turn capped by floodplain sediments immediately before 3,070 ±50 yr BP (TO-7353). The erosion at these two sites may actually coincide in time, representing the effects of increased Salmon River basin runoff during wetter climates (Davis and Muehlenbachs 2001). In both cases, middle Holocene-age deposits are either partially truncated, as in the case of 10IH395, or missing entirely, as seen at 10IH1220.

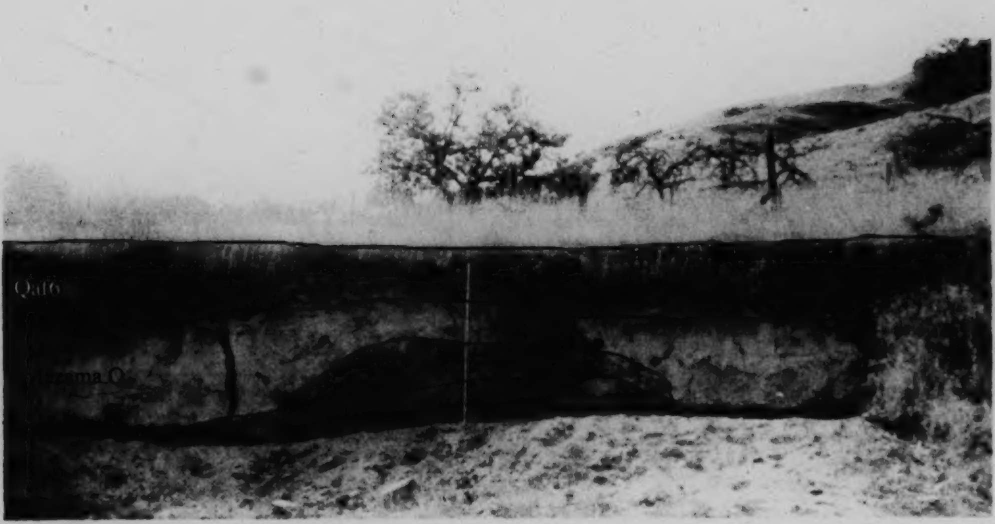

Figure 78. Overview of the SR-14 section showing an irregular eroded surface of an American Bar Soil horizon developed on Late Pleistocene-Holocene Alluvium (Qal4), which is overlain by Middle Holocene Alluvial Fan Gravels (Qaf5), Mazama O tephra, and Late Holocene Alluvial Fan Gravels (Qaf6). Scale is 2.0 m long.

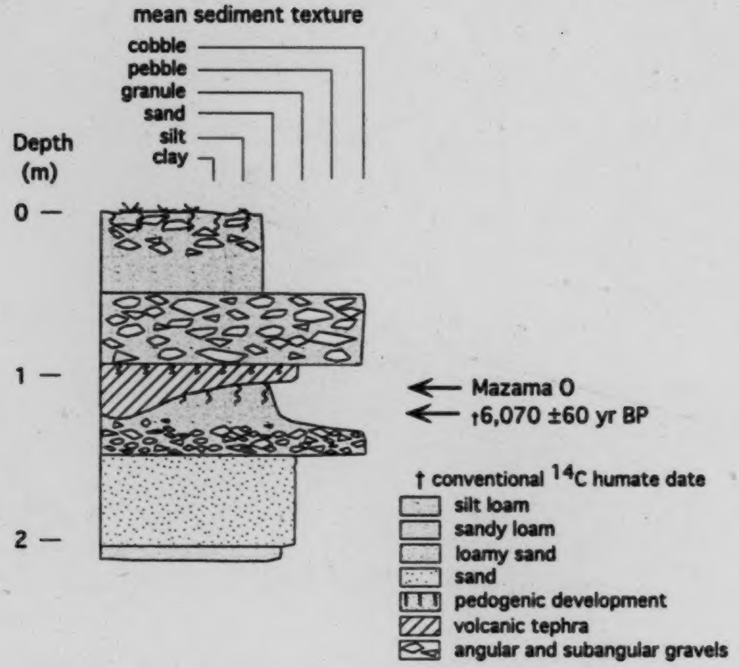
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
Mazama O
†6,070 ±60 yr BP
† conventional ^{14}C humate date
silt loam
sandy loam
loamy sand
sand
pedogenic development
volcanic tephra
angular and subangular gravels

Figure 79. Stratigraphy of SR-14.

Salmon River Canyon Geologic Processes: Internal and External Controls

Mass Movement Events

Structural adjustment is identified as the primary cause of major mass movement events in the study area such as the Devils Garden slide. Motion along the dip-slip fault line adjacent to the slide block would create the necessary instability to trigger the Devils Garden Slide event. There is no discernable correlation between major landslide events in the Lower Salmon River Canyon and external forcing mechanisms, such as climate. Smaller mass movment events that are confined to the displacement of surficial deposits can be attributed to gravitational forces acting upon saturated canyon slope deposits. Small slumps and mudslides occur on an annual basis in the canyon today, following intense spring rains and melting of winter snowpack. This process illustrates an obvious correlation between minor mass movement events and climate. It is expected that a greater frequency of mudslides, slope creep, and other slope processes that create minor mass movement deposits, will occur more frequently during periods with wet and cool climates (perhaps even seasonally). Thus the occurrence of these minor events may even be considered a proxy indicator of mesic climatic condition, where observed in the stratigraphic record of the study area.

Structural Adjustment

Holocene structural uplift is suspected in the area downstream of the normal fault that parallels Rock Creek and Graves Creek and extends through the area of the Devils Garden slide block. A sharp rise in the gradient of Holocene-age floodplain sediments is seen in the area of Bug Slope, which lies immediately downstream of the fault line (see Figure 5). Today, the Qal4 floodplain deposits contained in Bug Slope are found about 9 m (30') higher than the projected 2,000 yr BP-old floodplain gradient upstream of Rock Creek. This evidence confirms the existance of normal faulting in the area of Rock Creek and Devils Garden, as mapped by Gaston and Bennett (1979). Timing of the bedrock uplift below the mouth of Rock Creek may post-date the last period of floodplain deposition at 10IH1220 and 10IH2491 at ca. 2,000 yr BP. In this case, neotectonic displacement along the Rock Creek-Devils Garden fault line likely occurred during the last two millennia. Alternatively, reactivation of the Rock Creek-Devils Garden fault at ca.

2,000 yr BP triggered the incision of the Salmon River floodplain and remaining slide diamict. This downcutting undoubtedly acted as a catalyst for the reorganization of the Lower Salmon River alluvial system.

Pleistocene Alluvial Cycles

This study produced limited evidence of alluvial behavior dating to the Pleistocene. The available evidence is largely related to point bar formation within the context of floodplain development, which is coincident with large-scale canyon aggradation during the late Pleistocene. Bedrock uplift occurring throughout the Pleistocene probably helped to direct rates and timing of alluvial downcutting through bedrock deposits. Fluvial discharge probably was heightened during the transition from glacial to interglacial and interstadial environments, enhancing the erosive power of the Salmon River; higher sediment loads would also be expected during deglaciation, with much of the available fluvial energy used for sediment transport rather than erosion. The effect of neotectonic activity on Pleistocene alluvial cycles is likely to obscure the relationship between climate and hydrology in the Salmon River Canyon.

Holocene Alluvial Cycles

Lower Salmon River fluvial behavior was apparently quite constant during most of the Holocene. Between ca. 8,500 and ca. 2,000 yr BP, stratigraphic records from the lower portion of the study area between Bug Slope and the mouth of Rocky Canyon show a long record of low energy floodplain deposition. Farther upriver, low-energy floodplain sedimentation was less regular, with periods of sand deposition separating gravelly clay loam deposits. Thus, a more extensive and stable floodplain developed in the lower portion of the study area. While this Holocene floodplain deposition also occurred in the upper portion of the study area, there appears to be a greater degree of sedimentological variability there. These changes in floodplain sedimentation probably caused somewhat different riparian conditions to form in the upper portion during the Holocene, compared to the lower portion.

The differences in depositional style between the upper and lower portions of the study area appear to be related to the influence of slide diamict on the gradient of the Lower Salmon River channel. Before

2,000 yr BP, the slide diamict apparently remained as canyon fill to a point just downriver of the mouth of Rice Creek. The corresponding reduction in channel gradient caused by the diamict fill led to a reduction in Salmon River competency and velocity. Sediments accumulated in this low-energy zone much as they do in a lowland alluvial valley with low topographic relief. Upriver, the effects of the slide diamict fill on Holocene alluvial deposition were not as influential, it seems. Alluvial sediments seen in sections above McCulley Creek show coarser textures overall and periodic shifts to higher-energy deposition events.

It would seem that the style of Holocene alluviation in the study area was largely controlled by historical factors of canyon geology, more so than by climate or vegetation changes; although once an extensive riparian vegetation population was established, a positive feedback loop probably encouraged continued floodplain aggradation and hindered channel erosion. Despite the influence of internal geologic factors, other environmental influences on alluvial behavior cannot be overlooked. Holocene alluvial deposition can be explained as a combination of climate conditions, vegetation patterns and the effects of the pre-existing slide diamict on channel geometry.

Increased aridity in the canyon during the Holocene (Davis and Muehlenbachs 2001; Davis et al. n.d.) likely led to the reduction in vegetative biomass on canyon slopes and a diminished annual fluvial discharge. While the shrinking vegetative cover outside of the riparian zone undoubtedly contributed to increased rates of slope erosion and sediment input to the river, the Salmon River likely experienced difficulty transporting this sediment load with a reduced flow, particularly where riparian vegetation enhanced sediment capture. Under these conditions, the river would deposit the sediment it could not transport. A reduction in channel gradient caused by the presence of relict slide diamict would reduce the carrying capacity and competency of the river even further. This provided an area where excess sediment could be deposited, contributing to the development of a broad floodplain.

After 2,000 yr BP, the river downcut into its broad floodplain and through the remaining slide diamict. A change in alluvial deposition and an increased channel gradient are seen after this incision event. Post-2,000 yr BP alluviation is largely restricted to point bar development, with more extensive floodplain construction occurring only at the Hammer Creek Recreation Site. Stratigraphic exposures in the HC-2 Trench (see Figures 45 and 46) reveal a series of horizontally-bedded, fining-upwards depositional units, which appear to be related to periodic large-scale flooding events. This change in alluviation style is thought to represent a shift towards conditions operating in the modern Salmon River hydrological system. Annual snowpack accumulations in the mountainous uplands melt during the spring, producing a pronounced peak in fluvial discharge typically seen between the months of May and June. Extremely large flood events (i.e., in excess of 3681.6 cms (130,000 cfs)) are uncommon, roughly occurring at 100 year intervals. This hydrological regime that typifies the modern Salmon River likely operated for less than 2,000 radiocarbon years (cf. Chatters and Hoover 1986).

Tributary Canyon Discharge

The construction of alluvial fans at the mouths of tributary canyons along the Lower Salmon River varied much through time. The largest alluvial fans are located near normal faults. Vertical displacement along these fault lines would accelerate tributary erosion and the production of clastic debris. Discharge from tributary canyons is often dominated by angular diamict deposits, which are attributed to short-duration, high-intensity discharge events that move accumulated clastic material down into the main canyon, accumulating as an alluvial fan. Periods of marked tributary canyon discharge are seen to be preceded by soil development, which suggests the presence of a more mesic environment in the study area. A change in climate conditions from drier to wetter, with an associated increase in tributary stream discharge, could easily explain the increased rates of clastic deposition on tributary alluvial fans. This situation is seen in many locales through time: capping pedogenic development at SR-40; forming the base of the extensive T2 terrace in the upper portion of the study area, seen in areas like SR-37; underlying and in the middle of the SR-35 profile; in the middle of the SR-26-4 section; and resting above an eroded soil horizon at 10IH395.

Pleistocene Aeolian Deposition

Late Wisconsinan-age glaciers occupying the mountain ranges to the south and east of the study area probably introduced a large amount of fine sediment into the river system. During the Pleistocene and early Holocene, the Salmon River probably had the milky appearance of modern streams in northern regions that are laden with fine glaciogenic sediment. As the suspended sediment was deposited along the banks of the channel during seasonal floods, it was soon dried and reworked upslope as aeolian material.

Lower Salmon River Canyon Pleistocene loesses retain a grain size variability that appears to be related to aridity levels during the Pleistocene. Sand percentages in Pleistocene-age loesses vary in some sections between 35% and 71%. At SR-23, the fine sand fraction of loess closely mirrors changes in the stable oxygen-18 pattern of associated soil carbonates (Davis et al. n.d.). This relationship is interpreted as causal: increasing trends in aridity reflected in rising oxygen-18 compositions reflect the operation of climate conditions that favor the accumulation of fine sand in SR-23 loess. This increase in fine sand is thought to represent an increase in wind speed during different times in the Pleistocene, linking the influence of climate on aeolian sedimentation in the study area.

Holocene Aeolian Deposition

During the mid-Holocene, the close relationship seen between fine aeolian sand deposition and climate appears to break down by 6,000 yr BP. While oxygen-18 compositions suggest relatively warm and dry conditions (Davis et al. n.d.), fine sand deposition is reduced from earlier periods. Aeolian sediments dating to the middle Holocene period are generally finer in texture than deposits preceeding or following them. This may be partly related to the nature of the alluvial parent material from which the aeolian sediments are derived. Lower-energy alluvial sedimentation, which probably occurred during reduced discharge conditions of the middle Holocene, would provide an abundant supply of fine floodplain sediments. Accessibility of source materials is not enough to explain mid-Holocene textural changes, however, windspeed was probably reduced during the mid-Holocene, producing the finer-textured aeolian sediments. Although middle Holocene wind velocities were likely less than those operating during the late Pleistocene, the thickness of aeolian sediments at SR-23 dating to the last 6,000 yr BP suggests that dry and dusty conditions prevailed in the canyon throughout the Holocene. This sedimentation pattern is expected as the westerly storm track was diverted farther south than today during Pleistocene glacial and stadial periods, and shifted farther north during middle Holocene warming.

A 40 cm-thick deposit of Late Holocene Sandy Loess lies at the top of SR-23. Texturally, this upper deposit is coarser than loess dating to the mid-Holocene. Paleoclimate data gathered from the study area suggests that late Holocene conditions are cooler and more mesic (i.e., more similar to today) than during the middle Holocene (ca. 7,000 to 5,000 yr BP), which are associated with warmer and drier conditions than today. On this basis, it is difficult to use aeolian sedimentation records alone as a proxy record of general paleoclimate conditions. The mid-Holocene might be best thought of as hot, dry and dusty throughout a larger portion of the year, whereas the late Holocene probably experienced hot, dry conditions only during the summer months, similar to today.

At a depth of 200 cm below surface, SR-23 soil humates were AMS dated to 13,090 ±750 yr BP (TO-7817), while an AMS date of 14,930 ±1030 (TO-7818) is associated with soil humates at 300 cm below surface. Oxygen-18 records show that a warming and drying trend occurred between these two dates, reaching its climax at ca. 13,000 yr BP (Davis et al. n.d.). Fine sand sedimentation parallels the stable isotope compositions closely through this stratigraphic section, also reaching its highest percentages at 200 cm. Calculated insolation rates for the northern hemisphere suggest that seasonal inputs of solar radiation contrast greatly between 13,000 and 14,000 yr BP, resulting in much warmer summers and colder winters than today (Kutzbach 1987). Because of its close match with soil carbonate $\delta^{18}O$ signatures, the fine sand sedimentation record from SR-23 might be best interpreted as a proxy record of warm-season aeolian sedimentation.

Recommendations for Future Research

Future research will undoubtedly expand upon and clarify the information presented here. At this time, specific future research goals can be defined. Through the collection of more datable materials, future work should improve upon the chronostratigraphic ambiguities at the boundaries of various units. Efforts should be made to improve dating control for various units by seeking and finding datable charcoal or using alternative dating methods (e.g, thermoluminescence, optically-stimulated luminescene). A vacuum clearly exists regarding our knowledge of Lower Salmon River Canyon paleobotanical and paleofaunal populations during the Quaternary. Information on these components will help to better define the unique nature of riparian environments in the LSRC through time. Because landslide activity apparently produced unique depositional environments in the canyon, and because the study area is above the influence of the Bonneville and Missoula Floods, great potential exists for the preservation and investigation of unconsolidated Quaternary-age sediments.

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CHAPTER FOUR

LATE QUATERNARY ENVIRONMENTS OF THE LOWER SALMON RIVER CANYON, IDAHO, REVEALED IN SOIL CARBONATE STABLE ISOTOPE GEOCHEMISTRY AND AEOLIAN SEDIMENTATION RECORDS

A version of this chapter by L.G. Davis, K. Muehlenbachs, C.E. Schweger and N.W. Rutter was submitted for publication in Palaeogeography, Palaeoclimatology, Palaeoecology.

Introduction

Quaternary paleoenvironmental records from the Pacific Northwest are largely derived from studies of pollen records of lakes and bogs in plateau and upland settings (e.g., Barnosky 1984, 1985; Mehringer 1985; Sea and Whitlock 1995) and montaine glaciers (Kiver 1974; Burke 1978; Porter 1978; P.T. Davis 1988; Heine 1998). Despite the large amount of information available from regional paleoenvironmental proxy records, a perspective on Quaternary riparian ecology is largely absent in the Pacific Northwest. Although this is clearly due to the upland location of pollen and glacier studies, one must ask if the conditions reflected in these proxy records are applicable for studies of the nature and timing of vegetative change in riverine contexts. Faced with interpreting the vegetative response of riverine settings to late Quaternary climate change from examples provided in upland paleoenvironmental records, we may be missing important evidence of non-synchronous or unique changes in riparian zones.

In this paper we attempt to construct a high-resolution terrestrial late Pleistocene to Holocene record of climate and vegetation composition in western Idaho through a study of stable oxygen and carbon isotopes in pedogenic carbonate and from grain size variation of loess in the Lower Salmon River Canyon (LSRC). Studies of the stable isotope geochemistry of pedogenic carbonates have been conducted in several areas including central Africa (Cerling 1992), Nevada (Amundson *et al.* 1988), Texas (Humphrey and Ferring 1994), and Washington (Stevenson 1997). Many investigations of climate from loess grain size variability have been made, particularly in China (Ding *et al.* 1991). Our study in the LSRC shows how geologic deposits can be used to develop local-scale paleoclimate and paleovegetation records. Because the floodplain of the Lower Salmon River aggraded for much of the period between 25,000 and 2,000 yr BP, a long, high-resolution record of pedogenic carbonate is present where cumulic soils are formed. Loess deposits adjacent to the floodplain offer a contemporaneous record of aeolian grain size variability. Combined, these two records of paleoclimatic and paleovegetation conditions are evaluated from different perspectives. Correlations between datasets are interpreted as revealing a complex record of non-linear interactions among biotic and abiotic components of the LSRC ecosystem, which are compared with other regional paleoenvironmental records.

Study Area and Stratigraphic Sections

The LSRC is located approximately 90 km south of Lewiston, Idaho (Figure 80). Here, extensive Quaternary surficial deposits were created by alluvial, aeolian, and colluvial processes. Stratigraphic sections are located in the faces of historic placer mining cuts and in profiles exposed during archaeological excavations conducted in 1997.

In the study area, the Salmon River flows across Triassic metamorphosed basalts, andesites and volcaniclastics of the Wild Sheep Creek Formation (Vallier 1974), and Tertiary Grande Ronde (Reidel 1978) and Imnaha basalts (Holden 1974). During the late Quaternary, structural adjustment along a fault in the downriver portion of the study area roughly parallel to Rock Creek (Gaston and Bennett 1979), triggered a massive landslide originating from Devils Garden. Basaltic boulder diamict from the slide is widely distributed in the canyon between Rock Creek and American Bar, where it effected a lowering in the gradient of the Salmon River. Late Quaternary deposits predating 10,000 yr BP are dominated by aeolian sedimentation and point bar alluviation (L.G. Davis n.d.). After 10,000 yr BP, the Salmon River began a period of nearly continuous floodplain deposition in the study area. At ca. 2,000 yr BP the Salmon River incised into the Devils Garden landslide diamict that remained as canyon fill downstream of Rock Creek, resulting in the erosion of its floodplain (L.G. Davis n.d.).

Climate summary data are provided in Table 4 for stations in and near the LSRC. Riggins, Idaho, the only station in the canyon, located about 56 km upriver from the study area, today receives 42.7 cm of annual rainfall with an annual temperature of 19.2°C. Canyon vegetation is primarily composed of grasses (e.g., bluebunch wheatgrass (*Agropyron spicatum*)), annual bromes (*Bromes sp. tectorum, B. japonicus, B. brizaeformis, B. commutatus, B. rigidus*), and leafy plants like arrowleaf balsamroot (*Balsamorhiza sagittata*) and yarrow (*Achillea millefolium*). Thickets of various shrub species (e.g., hackberry (*Celtus douglasii*), smooth sumac (*Rhus glabra*), ninebark (*Physocarpus malvaceous*), hawthorn (*Crataegus douglasii*)), mountain mahogany (*Cercocarpus ledifolius*), and isolated stands of ponderosa pine (*Pinus ponderosa*) and douglas fir (*Pseuduotsuga menziesii*) are seen in tributary drainages with annual or seasonal streamflow and on east and north-facing slopes (Horton 1972). The maximum depth of wetting and carbonate precipitation in canyon soils is approximated by the amount of annual rainfall (Jenny 1941);

Station	Ann. T	TDJF	TMAM	TJJA	TSON	Ann. P	PDJF	PMAM	PJJA	PSON
Cottonwood	13.2	2.6	12.4	24.3	13.6	56.9	12.7	18.3	13.5	12.5
Lewiston	17.4	5.5	16.9	29.7	17.3	32.5	8.4	9.7	7.1	7.6
Boise	17.2	4.4	16.7	30.2	17.7	30.2	10.2	9.4	3.8	7.1
Nezperce	13.8	2.8	12.8	25.3	14.2	53.9	11.9	17.5	11.7	12.7
Grangeville	8.0	-0.7	7.0	17.5	8.2	60.7	11.2	21.6	13.7	14.2
Riggins	19.2	6.9	18.8	31.7	19.3	42.7	9.4	14.2	9.1	10.2

Table 4. Climatological data from selected stations in and around the Salmon River basin, Idaho (Western Regional Climate Center 2000). Annual (Ann.) and seasonal (DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November) Temperature (T) shown in degrees C. Annual and seasonal precipitation (P) shown in centimeters.

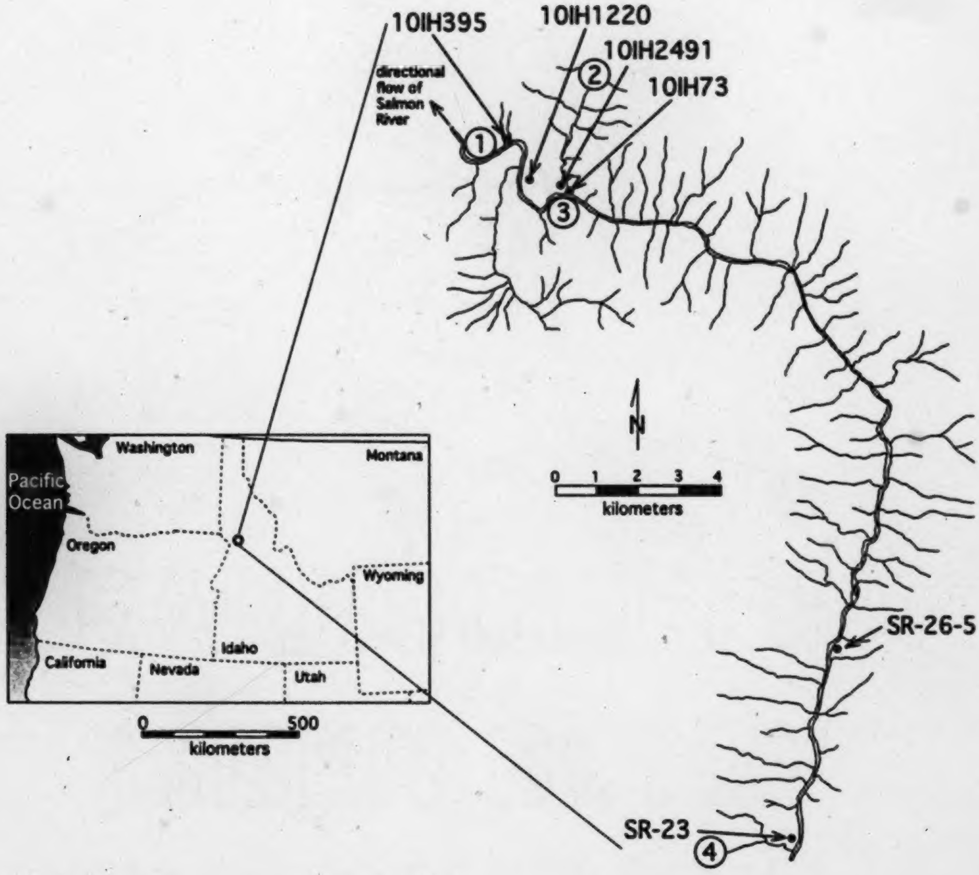
10IH395
10IH1220
10IH2491
10IH73
directional flow of Salmon River
①
②
③
N
0 1 2 3 4
kilometers
SR-26-5
SR-23
④
Pacific Ocean
Washington
Montana
Oregon
Wyoming
Idaho
California
Nevada
Utah
0 500
kilometers

Figure 80. Location of the Lower Salmon River Canyon study area in the Pacific Northwest, showing the position of archaeological sites (e.g., 10IH73), stratigraphic sections (e.g., SR-26-5) and other areas mentioned in text: (1) American Bar; (2) Rock Creek; (3) Devils Garden; (4) Hammer Creek.

however, the actual depth of wetting in canyon soils is considerably less than the amount of precipitation, due to the low intensity and short duration of precipitation events and moderate rates of regional evaporation (i.e., greater than or equal to a range of 148-164 cm mean annual pan evaporation for the study area [United States Environmental Data Service, 1968]). Seasonally, the canyon receives most of its rainfall in the late winter and spring months, with hot, dry summers and cool, relatively dry winters.

In order to develop a time-series approach to soil carbonate stable isotopic values and rates of aeolian sedimentation, stratigraphic sections exhibiting cumulic depositional histories were chosen for study. Two geologic sections and four archaeological sites designated as SR-26-5, SR-23, and 10IH73, 10IH395, 10IH1220, and 10IH2491, respectively (Figure 80), yielded records of soil carbonate and aeolian sediments spanning the last 25,000 yr BP.

SR-26-5

An exposure in a large alluvial fan contains multiple deposits of loess, colluvium, alluvial sand, and volcanic tephras (Figure 81). Upper limiting ages for loess deposition are provided by radiocarbon dates of 10,740 ±220 yr BP (TO-7351) and 11,320 ±90 yr BP (TO-7352) (Table 5). The presence of a lower oxidized paleosol with desiccation cracks, considered to be a local equivalent to the Late Wisconsinan-age Washtucna Soil identified in the Palouse region of eastern Washington where it is dated between ca. 18,000 yr BP and ca. 27,000 yr BP (Busacca and McDonald 1994:Figure 2), allows for an age assessment.

SR-23

Aeolian deposits of carbonaceous silt loam and sandy loam are located on the lower flanks of the canyon near Hammer Creek. These sediments overlie fine to coarse, rounded, mixed-lithology alluvial gravels (Figure 81) and extend upslope, blanketing colluvium and bedrock in many places. Three AMS dates on soil humate range between 6,040 ±620 yr BP (TO-7816) and 14,930 ±1,030 yr BP (TO-7818) (Table 5). An erosional unconformity is present in the middle of the profile immediately above the position of a 13,090 ±750 yr BP (TO-7817) humate date.

Site/Section	Provenience	Method	Sample #	Material	Uncalibrated ^{14}C age
SR-23	100-110 cm	AMS	TO-7816	soil humate	6,040 ±620
SR-23	190-200 cm	AMS	TO-7817	soil humate	13,090 ±750
SR-23	280-290	AMS	TO-7818	soil humate	14,930 ±1,030
SR-26-5	A/1	AMS	TO-7351	char. wood	10,740 ±220
SR-26-5	A/2	AMS	TO-7352	char. wood	11,320 ±90
SR-26-5	505-510 cm	Conv.	Tx-9137	soil humate	25,270 ±530
10IH73	73/279, A, L7	AMS	Beta-114952	wood char.	8,430 ±70
10IH73	SW/18	AMS	TO-7349	wood char.	11,410 ±130
10IH395	120-130 cm	Conv.	Tx-9138	soil humate	6,070 ±60
10IH395	140 cm	Conv.	Tx-9269	mussel shell	8,360 ±80
10IH1220	A/7	AMS	TO-7353	char. wood	3,070 ±50
10IH1220	250-260 cm	AMS	TO-7815	soil humate	8,030 ±310
10IH1220	190-200 cm	AMS	TO-7814	soil humate	9,170 ±180
10IH1308	1308/32, 1, L5	Conv.	Tx-9271	mussel shell	3,340 ±60
10IH2491	2491/D1,D,L4	AMS	Beta-114808	wood char.	1,960 ±40
10IH2491	2491/67,D,L7	AMS	Beta-114805	wood char.	2,010 ±40
10IH2491	2491/50,D,L2	AMS	Beta-114804	wood char.	2,050 ±40
10IH2491	2491/50,D,L13	AMS	Beta-114806	wood char.	6,780 ±50

Table 5. Radiocarbon dates from stratigraphic sections used in this study.

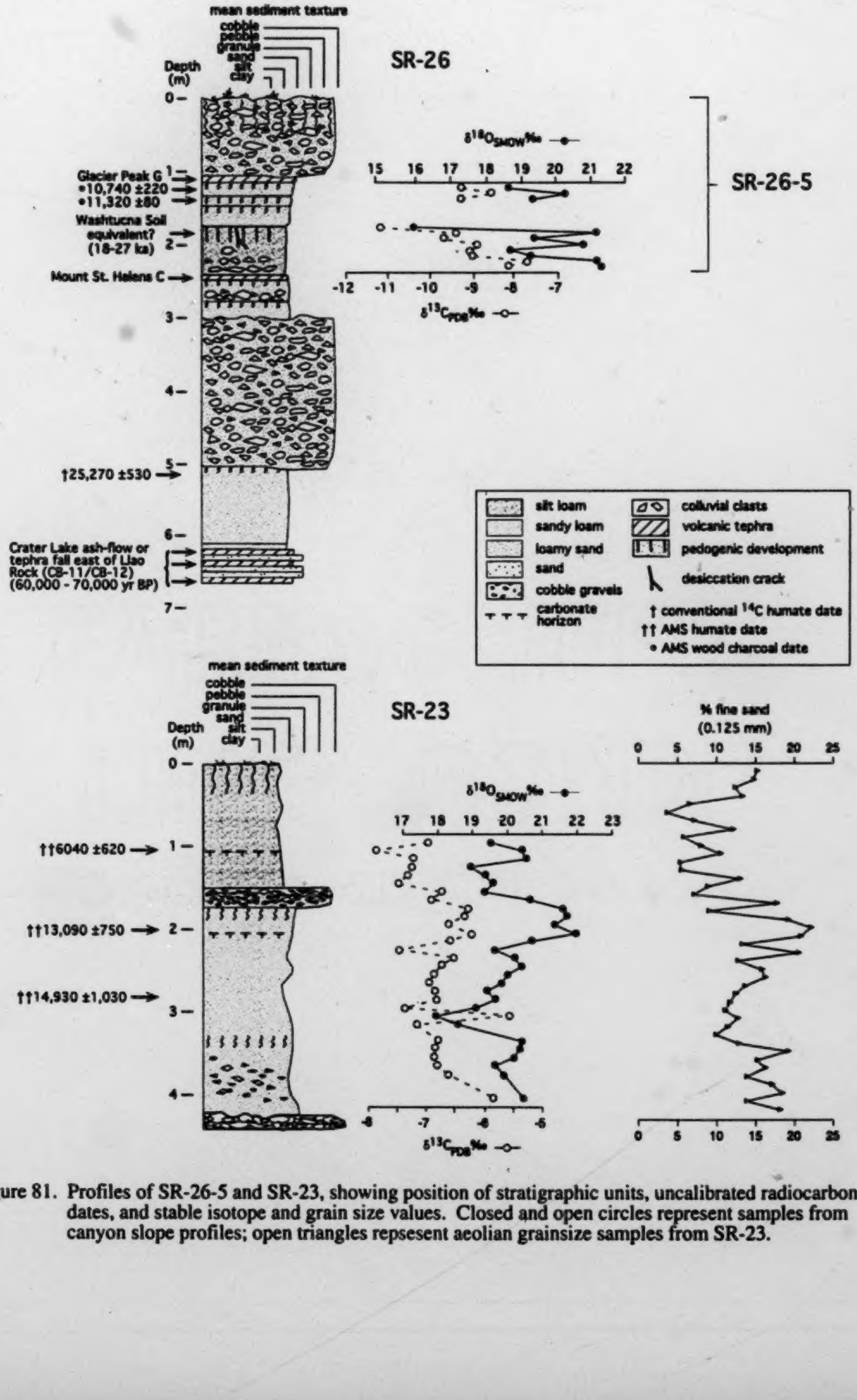

Figure 81. Profiles of SR-26-5 and SR-23, showing position of stratigraphic units, uncalibrated radiocarbon dates, and stable isotope and grain size values. Closed and open circles represent samples from canyon slope profiles; open triangles repsesent aeolian grainsize samples from SR-23.

10IH73 Unit A

Archaeological excavations encountered a series of Salmon River floodplain and aeolian deposits separated by sharp boundaries (Figure 82). Eight radiocarbon dates were produced from excavation Unit A at 10IH73, although not all are used to establish a chronological framework for site sedimentation (Table 5), due to possible vertical displacement of samples by bioturbation, anthropogenic disturbance and potential contamination of bone samples.

10IH395 Unit B

Stratigraphic profiles in archaeological excavations showed a series of alluvial sands overlain by a silt loam Salmon River floodplain deposit (Figure 82), which contained a river mussel shell (*Margaritifera falcata*) dated to 8,360 ±80 yr BP (Tx-9269). Erosion of the floodplain occurred after the formation of soil humates at 6,090 ±60 yr BP (Tx-9138), followed by redeposition of Mazama set O tephra and later capped by alluvial fan growth from a nearby tributary drainage.

10IH2491 Unit D

This archaeological site produced a Holocene record of tributary floodplain aggradation dating immediately before 6,780 ±50 yr BP (Beta-114806) and lasting until ca. 1,960 ±40 yr BP (Beta-114808) (Table 5). The stratigraphy is comprised of three parts: (1) a basal unit of subangular to subrounded clast-supported boulders; (2) a sandy loam with occasional subrounded to subangular basalt gravel clasts and carbonate filaments; (3) a massive, quartz-rich, medium sand with colluvial clastic content and modern soil development towards the top of the profile (Figure 82).

10IH1220 Unit A

A test pit placed at this archaeological site revealed a stratigraphic sequence of Salmon River floodplain sediments similar to that seen at 10IH2491, dating between 9,170 ±180 yr BP (TO-7814) and 3,070 ±50 yr BP (TO-7353) (Table 5). The four-part stratigraphy encountered here includes: a lower subrounded to subangular gravel unit (1), overlain by silty loam sediments with carbonate filaments (2),

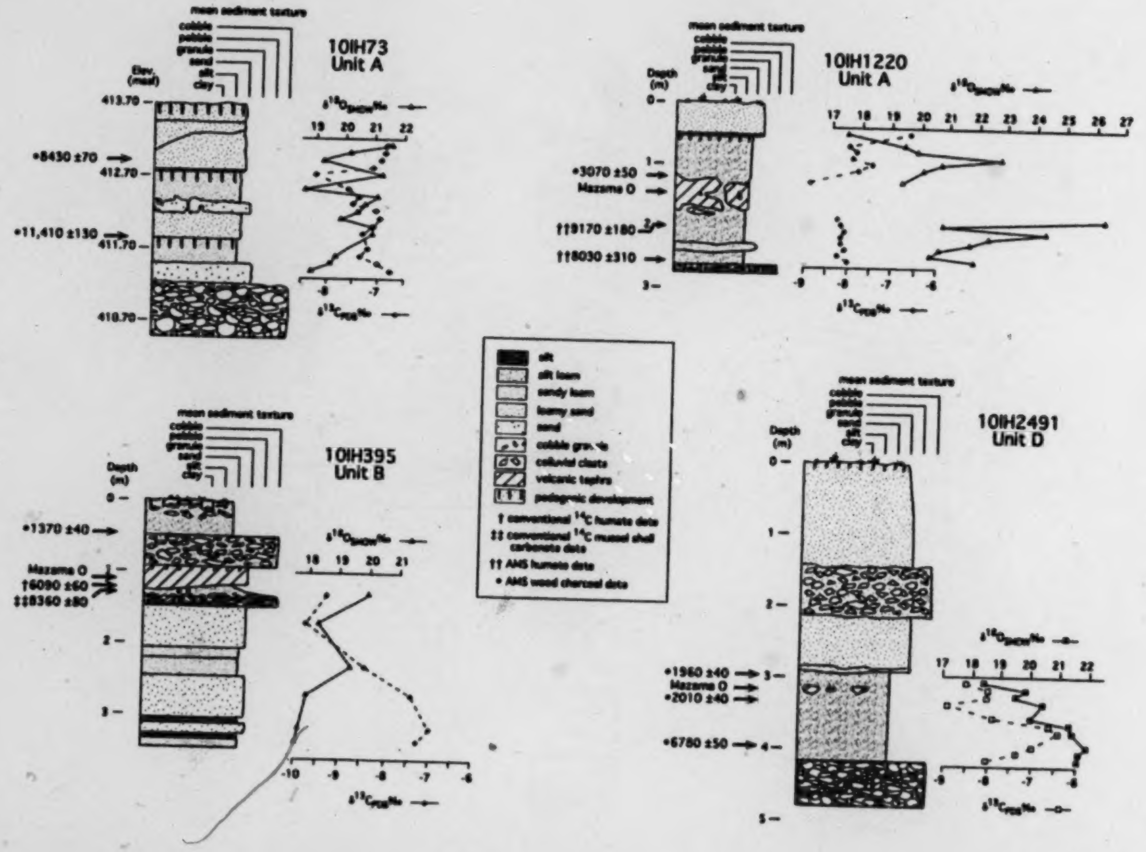

Figure 82. Profiles of 10IH73 Unit A, 10IH1220 Unit A, 10IH395 Unit B and 10IH2491 Unit D showing position of stratigraphic units, uncalibrated radiocarbon dates, and stable isotope and grain size values. Closed triangles and open diamonds are from Salmon River floodplain sections; closed and open squares are from tributary floodplain deposits.

that show an erosional contact with a thick unit of redeposited Mazama set O tephra (3), which is buried by more carbonaceous silt loam (4), and a massive medium quartzitic sand (5) (Figure 82).

Methods

Stable Isotopes

Carbonate samples collected at stratigraphic sections from nodules or rhizoliths were examined under low-power microscopy to establish the presence of authigenic carbonate minerals and to look for evidence of diagenesis (e.g., penetration of soil water into nodules through cracks). Soil carbonates were reacted *in vacuo* with H_3PO_4 at 25.3°C; the resultant CO_2 was cryogenically extracted and analyzed by a Finnegan MAT 252 mass spectrometer, which has an internal error of ±0.1‰ for carbonates. Isotopic compositions of $\delta^{18}O$ were reported in parts per mil (‰) relative to Standard Mean Ocean Water (SMOW) (Baertschi 1976) and $\delta^{13}C$ compositions were reported in parts per mil (‰) relative to the carbonate standard Peedee Belemnite (PDB) (Craig 1957).

Basis For Interpretation

In this study, we assume pedogenic carbonate is formed in equilibrium with soil CO_2 below ca. 20-30 cm in a soil profile (Cerling 1984), that no significant post-depositional diagenetic change occurred in soil carbonates due to low limits of soil water percolation, and that the stratigraphic position of soil carbonate in cumulic sedimentation contexts can be related to a time series based on normalized rates of deposition. As well, we follow Cerling (1992), and Cerling and Quade (1993) in their view of the $\delta^{18}O$ signature of soil carbonate as related to the isotopic character of meteoric water, which is influenced by regional precipitation regimes and evaporation of near-surface soil water, and Cerling (1984) by interpreting the $\delta^{13}C$ signature as related to the relative proportion of plants using the C_4 photosynthetic pathway.

Cerling (1992), and Cerling and Quade (1993) explain correlations between $\delta^{18}O$ and $\delta^{13}C$ compositions in soil carbonate as a result of temperatures and aridity affecting plants with the C_3 photosynthetic pathway. Decreased $\delta^{18}O$ and $\delta^{13}C$ reflect more temperate conditions. This occurs as lowered atmospheric temperatures deplete $\delta^{18}O$ in meteoric water during more frequent precipitation events, and fractionation effects on pedogenic carbonate fractionation occur under lower soil temperatures. Under more xeric conditions, the opposite effect is expected. Under this scenario, greater $\delta^{18}O$ composition in rainfall resulting from fewer precipitation events, is combined with increased soil temperatures and rates of evaporation in near-surface soil water to produce heightened $\delta^{18}O$ composition in soil carbonates (Cerling 1992; Cerling and Quade 1993). Just as increased compositions of $\delta^{18}O$ in soil carbonate are associated with arid conditions, rising $\delta^{13}C$ values reflect the expansion of drought-tolerant C_4 plants at the expense of their more mesic C_3 counterparts (Cerling 1992).

Study of shallow groundwater $\delta^{18}O$ and δD in the area of Pullman, Washington and Moscow, Idaho USA by Larson (1996) established a local meteoric water line, with a slope of $\delta D = \delta^{18}O\ (6.68) - 18.62$. Using O'Neil et al's (1969) equation describing the relationship between the $\delta^{18}O$ of water and calcite, the isotopic values of LSRC soil water and soil carbonates were calculated and plotted relative to Pullman-Moscow Basin meteoric water $\delta^{18}O$ values (Figure 83). The relative isotopic enrichment of LSRC soil water and soil carbonates relative to Pullman-Moscow Basin shallow groundwater points to the influence of evaporation in the fractionation process (Welhan 1987:Figure 1). Because local geographic conditions in the study area influence rates of solar insolation, soil water availability, and evaporation we expect that soil carbonates of the same age collected from different parts of the canyon (e.g., north-facing vs. south-facing slopes, or well-drained loess deposits on slopes vs. well-watered alluvial floodplains) will show synchronic variability in $\delta^{18}O$ composition, which reflect the differential operation of microclimatic and hydrological processes. Thus, the overall trend of soil carbonate $\delta^{18}O$ variability gives a detailed perspective on canyon paleoenvironments.

Aeolian Grain Size Variability

Extensive deposits of sandy loess from SR-23 were sampled for granulometric analysis. Sediment samples were first oven dried at 60° C for 24 hours. The dried samples were carefully disaggregated by hand in a mortar and 100 g of sediment was passed through a series of U.S. Standard wire mesh sieves to separate coarse sand to silt-sized fractions (+1 to +4 phi; US Standard Sieve sizes 35, 60, 120, 230, and pan) (after

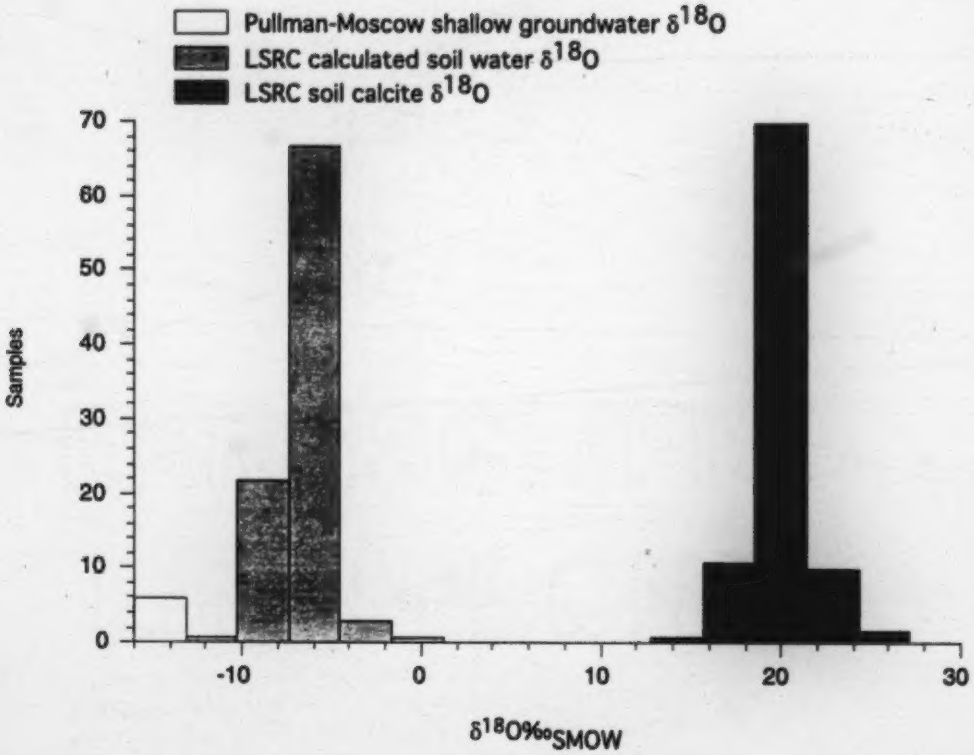

Figure 83. Comparison of the stable oxygen isotope composition of Pullman-Moscow shallow groundwater (Larson 1996), Lower Salmon River Canyon (LSRC) soil water, and LSRC soil calcite. Assuming a mean summer temperature of 31.7° C (same as Riggins, Idaho), the $\delta^{18}O$ of the soil water that LSRC calcite formed from is calculated as 26.6‰, following the method of O'Neil et al. (1969). Variance in LSRC soil water is established by difference between the calculated soil water value and the $\delta^{18}O$ of LSRC soil calcite. This graph shows a progressive enrichment of $\delta^{18}O$ in Pullman-Moscow shallow groundwater, LSRC soil water, and LSRC soil calcite, pointing to the role of local evaporation in the fractionation of LSRC soil carbonates.

Wentworth 1922). Each stack of sieves was mechanically shaken for 15 minutes with resulting size fractions weighed individually.

Basis For Interpretation

Canyon sediments were identified as aeolian in origin based on multiple criteria, including their lack of stratification or bedding structures, angle of repose (typically greater than 10%), and abraded and fractured clastic surface morphology. Sediments deposited in the floodplain zone of the Lower Salmon River provided a material source for short-distance aeolian transport, resulting in the accumulation of sandy loess on the lower flanks of the canyon (cf. Pye 1995). This model of aeolian transport is supported by scanning electron microscopy, which shows abrasion and fracturing on the edges and faces of angular to subangular sand grains (Figure 84). On this basis, the frequency of grain size classes in SR-23 aeolian sediments are organized in a time series and evaluated to reveal potential paleoclimatic indicators; this mode of reasoning was used to interpret aeolian sedimentation records in China's Loess Plateau (e.g., Ding *et al.*, 1991).

Establishing a Time Series

Radiocarbon dates produced from the six study sections form the primary basis for placing isotope and grain size samples in a temporal context (Table 5). In order to organize the isotope and grain size samples in a time series, sedimentation rates were interpolated from the stratigraphic depth of radiocarbon dates. Considering the limited depth of soil wetting in the study area we used a 20 cm depth of precipitation for soil carbonates. By shifting the stratigraphic position of soil carbonate samples upwards by 20 cm we adjusted for temporal asynchroneity. In the case of grain size samples from SR-23 no adjustment was made as the vertical position of samples can be directly related to a normalized time series. A few minor adjustments were made to the chronological framework after comparing temporally-corresponding isotopic and grain size records of different sections in order to attain a better fit among datasets and to aid in the graphical presentation of the data.

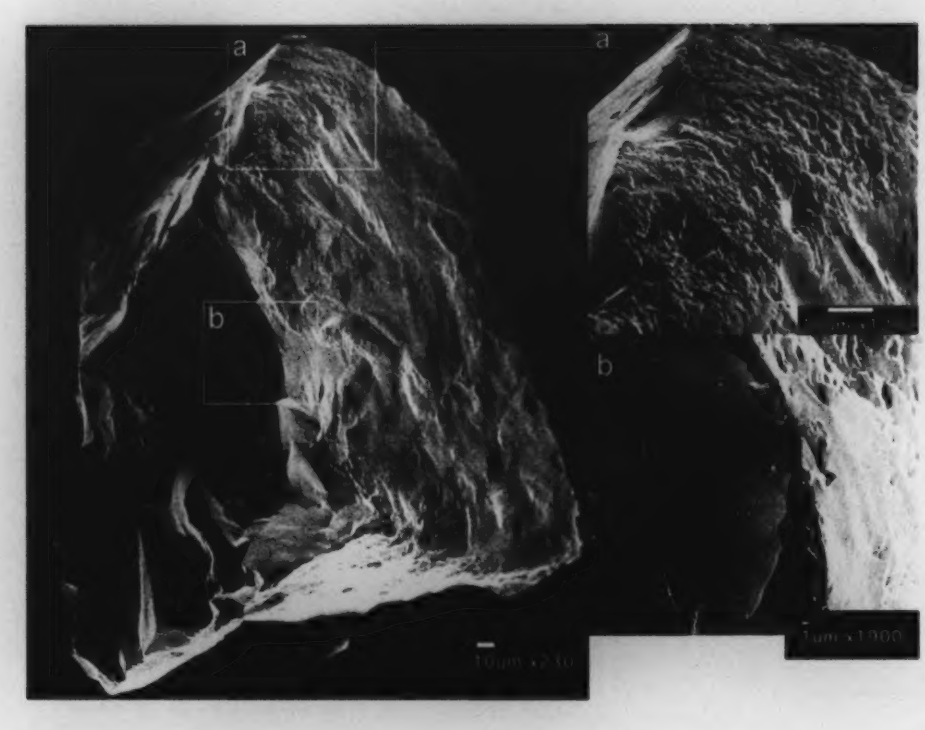
a
b
a
b
10µm x230
1µm x1000

Figure 84. Representative SEM images of sand grain morphology from SR-23. Detail of abrasion (a) and conchoidal fracturing (b).

Results and Discussion

Soil carbonate isotopes from all sections (Tables 6 and 7) show a total range in $\delta^{18}O$ of 11.3‰ (from 15.0‰ to 26.3‰). The greatest variation in $\delta^{18}O$, in any one section, was seen at 10IH1220, which spanned 8.8‰ (from 17.5‰ to 26.3‰). Total variation in $\delta^{13}C$ covered 5.2‰ (from -10.4‰ to -5.2‰) with the largest variability of all sections seen at SR-26-5 covering 4.5‰ (from -10.4‰ to -5.9‰).

Sections positioned on canyon slopes (SR-26-5 and SR-23) and in tributary floodplains (10IH2491) show stronger positive covariation between $\delta^{18}O$ and $\delta^{13}C$ (Figure 85) than among Salmon River floodplain sections, with greater proportions of C_4 plants appearing on slopes during periods of increased $\delta^{18}O$ composition. This positive covariation is interpreted as the direct effect of xeric climate conditions on canyon vegetation. Soil carbonates from 10IH73 and 10IH2491 show a low correlation between $\delta^{18}O$ and $\delta^{13}C$, suggesting that the proportion of C_3 plants in the Salmon River floodplain zone is not directly influenced by climatic effects. Our interpretation of this riparian pattern is that water retained in the finer floodplain sediments and the underlying groundwater zone provides an adaptive buffer for phreatophytic and mesic plants, allowing for the maintenance of higher C_3 populations during xeric periods. While vegetation patterns in areas lacking a constant or reliable water source are seen to shift rapidly and in proportion to climate changes, the flora of the Salmon River riparian zone apparently changed very little through time.

Isotopic values organized in a time series show the relationship between climate and vegetation patterns in the LSRC (Figure 86). In the case of 10IH73, the trend in $\delta^{13}C$ composition lags behind the pattern of $\delta^{18}O$ values. This is thought to be linked to an asynchronous relationship between climate conditions and hydrological response in the floodplain. The isotopic data from 10IH1220 suggests that where the gradient of the Salmon River channel was greatly reduced, soil water probably was more plentiful for plant growth in the floodplain during most of the Holocene, thus no lead-lag pattern is seen. Data from 10IH2491 shows that tributary floodplains were more prone to desiccation, as evidenced by a closer covariance between $\delta^{18}O$ and $\delta^{13}C$. This is expected as few tributary canyons in the study area maintain perennial streamflow today, and of those, discharge is extremely reduced during the summer months.

Stratigraphic section	Depth (cm) BD	Elevation (masl)	Soil δ ^{18}O‰	Soil δ ^{13}C‰
SR-26	10		18.7	-9.3
SR-26	20		20.3	-8.5
SR-26	30		19.4	-9.3
SR-26	80		15.0	-10.4
SR-26	90		17.2	-6.1
SR-26	100		16.8	-7.5
SR-26	110		17.9	-6.3
SR-26	120		17.6	-8.0
SR-26	130		17.6	-7.6
SR-26	140		19.3	-6.0
SR-26	150		18.5	-5.9
10IH73		413.50	19.9	-7.5
10IH73		413.30	20.1	-7.5
10IH73		413.20	20.0	-7.3
10IH73		413.10	21.6	-6.9
10IH73		413.00	20.1	-6.9
10IH73		412.90	19.2	-7.0
10IH73		412.80	20.2	-7.1
10IH73		412.70	21.2	-8.2
10IH73		412.50	18.6	-7.6
10IH73		412.40	21.1	-7.4
10IH73		412.30	20.7	-7.5
10IH73		412.20	20.4	-7.1
10IH73		412.10	19.8	-7.0
10IH73		412.00	20.9	-7.1
10IH73		411.90	20.9	-7.3
10IH73		411.70	20.0	-7.2
10IH73		411.60	19.7	-7.4
10IH73		411.50	19.5	-7.0
10IH73		411.40	18.8	-6.8
10IH2491	50		18.2	-8.6
10IH2491	60		19.4	-8.1
10IH2491	70		19.1	-8.2
10IH2491	80		20.0	-8.9
10IH2491	100		19.6	-8.0
10IH2491	110		20.7	-7.0
10IH2491	120		20.8	-6.8
10IH2491	140		21.2	-7.3
10IH2491	150		21.0	-7.6
10IH2491	160		21.0	-8.2
10IH1220	50		17.5	-6.6
10IH1220	60		19.4	-7.9
10IH1220	70		19.0	-7.7
10IH1220	80		19.9	-7.8
10IH1220	90		22.7	-7.9
10IH1220	100		20.7	-7.5
10IH1220	110		20.1	-7.8
10IH1220	130		19.4	-8.9
10IH1220	190		26.3	-8.3
10IH1220	200		20.8	-8.2
10IH1220	210		24.3	-8.1
10IH1220	220		22.4	-8.2
10IH1220	230		21.7	-8.2
10IH1220	240		20.6	-8.1
10IH1220	250		20.3	-8.3
10IH1220	260		21.8	-7.9
10IH395	130		20.0	-9.3
10IH395	170		18.3	-9.8
10IH395	230		19.4	-8.5
10IH395	270		17.9	-7.4
10IH395	290		21.3	2.8
10IH395	316		17.7	-7.0

Table 6. Stable isotope geochemistry results from SR-26-5, 10IH73, 10IH2491, 10IH1220 and 10IH395. Depth is reported in centimeters below datum (BD) and as elevation in meters above sea level (masl). Depth or elevation intervals with no isotopic data are omitted.

Depth cm (BS)	Soil $\delta^{18}O$‰	Soil $\delta^{13}C$‰	% Fine Sand
110	19.5	-7.0	10.4
120	20.4	-7.9	5.3
130	20.6	-7.2	5.4
140	19.0	-7.3	13.0
150	19.4	-7.3	8.9
160	19.6	-7.5	7.1
170	19.4	-6.7	17.6
180	20.7	-6.9	9.0
190	21.6	-6.3	19.1
200	21.7	-6.3	22.1
210	21.4	-6.6	20.8
220	21.9	-6.2	13.3
230	20.7	-6.6	20.4
240	21.6	-6.4	12.6
250	20.2	-6.5	15.8
260	20.4	-6.7	16.2
270	20.0	-6.9	13.5
280	19.8	-7.0	12.3
290	19.4	-6.9	11.6
300	19.7	-6.8	11.1
310	19.1	-7.4	12.6
320	18.7	-7.0	11.4
330	18.6	-7.2	9.8
340	16.7	-5.2	12.8
350	20.4	-6.8	19.1
360	20.4	-6.9	15.1
370	20.2	-6.9	16.2
380	19.6	-6.8	13.9
390	19.9	-6.7	17.0
400	20.1	-6.6	18.4
410	20.2	-6.4	13.9
420	20.5	-5.8	18.1

Table 7. Stable isotopic composition of soil carbonate, fine sand frequency at SR-23. Depth is reported in centimeters below surface of profile.

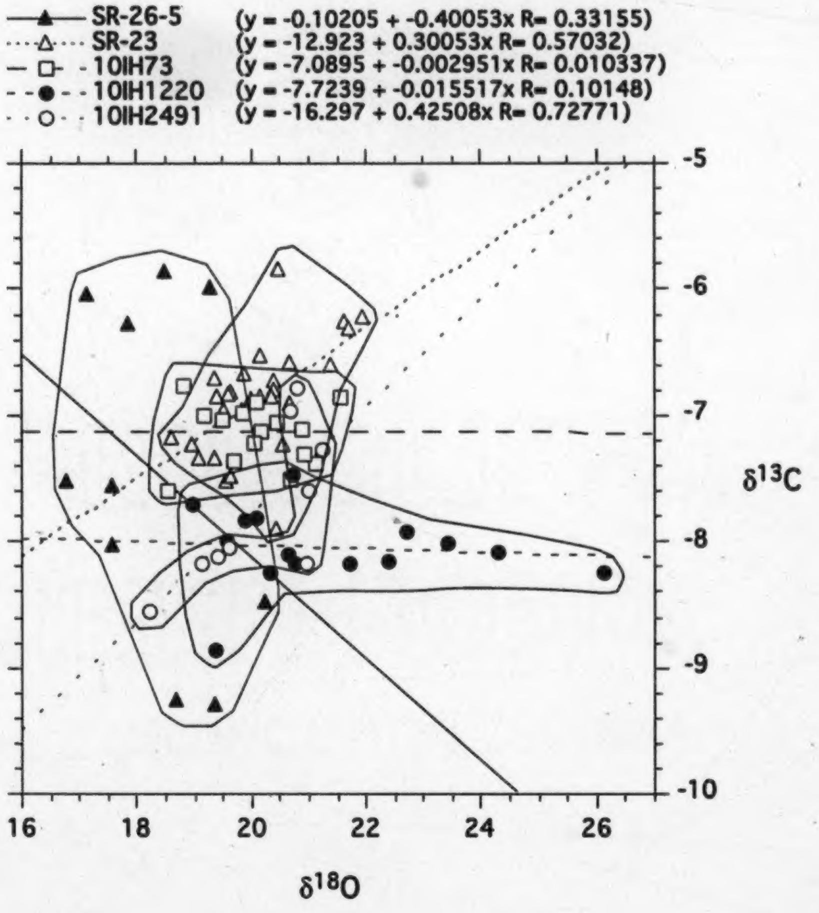

Figure 85. Cross plot of soil carbonate $\delta^{18}O$ vs. $\delta^{13}C$ for all stratigraphic profiles.

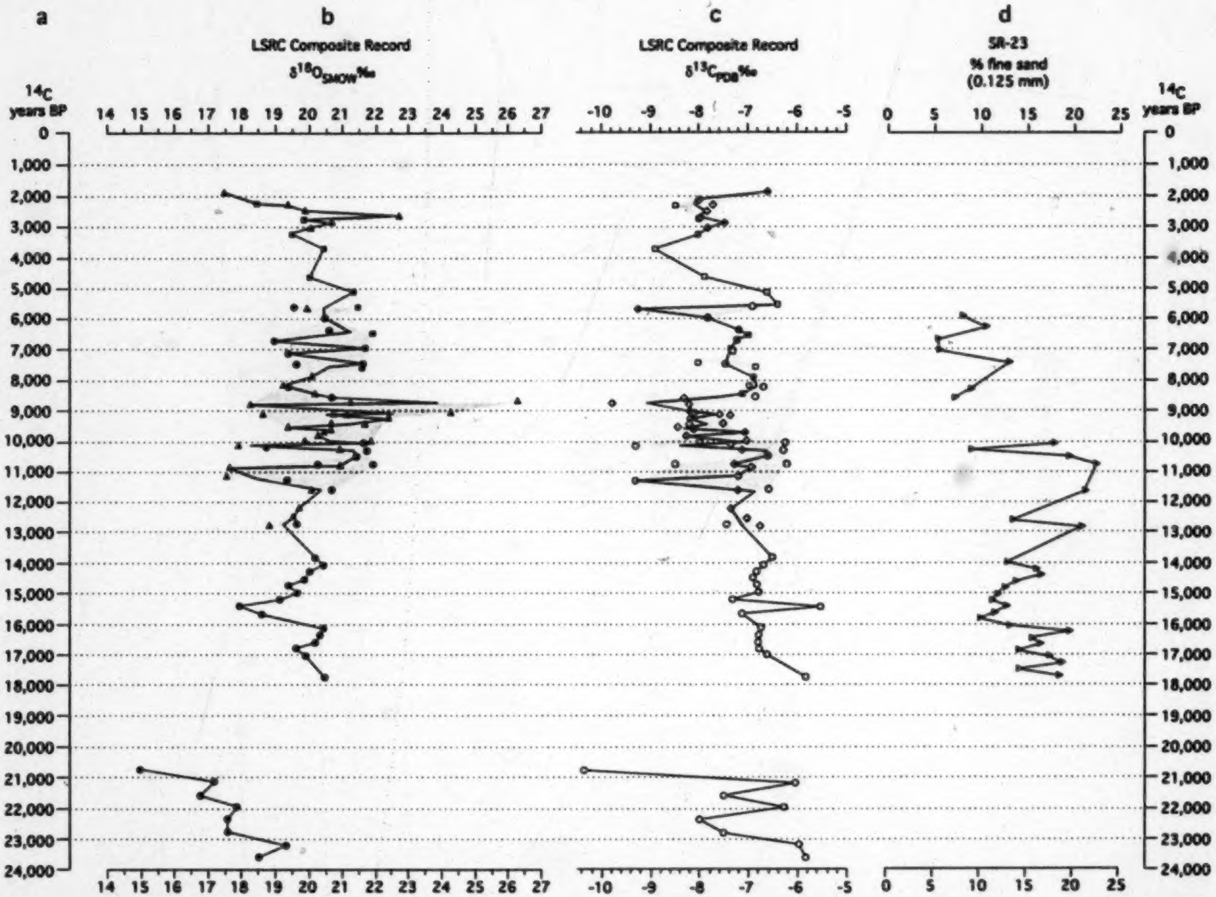

Figure 86. Soil carbonate $\delta^{18}O$ (b) and $\delta^{13}C$ (c) and aeolian grain size flux data (d) organized by uncalibrated ^{14}C years BP (a). Symbol patterns follow Figs. 81 and 82. Shaded portions span the range of synchronous isotopic variation in different canyon locations. Solid line tracks the average isotopic value for synchronous data points.

Late Pleistocene Environments

Prior to 21,000 yr BP, $\delta^{18}O$ records show an oscillatory decline in isotopic composition, suggesting a cooling trend, while $\delta^{13}C$ values from canyon slope contexts fluctuate between C_3 and C_4 dominated flora populations. Compositions of $\delta^{18}O$ are seen at their lowest immediately after ca. 21,000 yr BP record, representing the coldest conditions on record, and are associated with a flora almost entirely composed of C_3 plants. Between ca. 17,000 and ca. 16,000 yr BP, fine sand deposition fluctuates between 15% and 20% at SR-23, suggesting a period of heightened aridity. Declining $\delta^{18}O$ compositions point to a return to somewhat colder climates between ca. 16,000 and ca. 15,000 yr BP. Fine sand deposition and $\delta^{18}O$ values rise between ca. 14,500 and 10,000 yr BP, marking a gradual warming and drying trend. Canyon slopes show a reduced proportion of C_3 flora after ca. 18,000 yr BP, which continues on until 11,000 yr BP. Immediately before 11,000 yr BP, $\delta^{18}O$ and $\delta^{13}C$ compositions are lower, suggesting a brief and rapid resurgence of cold conditions. This isotopic shift is also accompanied by increased aeolian sand deposition, suggesting a corresponding aridity increase in the canyon. Between 11,000 and 10,000 yr BP, $\delta^{18}O$ and $\delta^{13}C$ compositions rise and remain relatively high, suggesting the presence of warmer conditions, which correspond with the highest rates of fine sand sedimentation (and aridity) on record. These changes in canyon proxy records from 11,000 to 10,000 yr BP match the timing and magnitude of the Younger Dryas climate event, as seen in Europe, North America, and elsewhere (e.g., Berglund 1979; Overpeck et al. 1989; Engstrom et al. 1990; Flower and Kennett 1990; Linsley and Thunell 1990; Kudrass et al. 1991; Mathewes et al. 1993; Peteet et al. 1990; Reasoner et al. 1994; Holliday 2001).

Late Pleistocene - Early Holocene Environments

Although $\delta^{18}O$ and $\delta^{13}C$ values suggest relatively stable warmer and drier climates dominated in the LSRC between 11,000 and 10,000 yr BP, unstable climatic and vegetation patterns preceed these conditions. Proxy records suggest climate conditions varied widely from cold temperatures at 11,000 yr BP, to warmer and drier conditions between 11,000 and 10,000 yr BP, returning again to colder conditions at ca. 10,000 yr BP. Greater vegetative stability is seen between 10,000 and 9,000 yr BP as $\delta^{13}C$ compositions show little variability compared to the broad fluctuations in corresponding $\delta^{18}O$. Immediately before

11,310 ±80 yr BP (TO-7358) the Lower Salmon River began to build a broad floodplain--evidence of which is widespread in the study area by ca. 10,000 yr BP (L.G. Davis n.d.)--and probably contributed to increased C_3 percentages at 10IH1220 and 10IH73. Aeolian sand influx at SR-23 remains high through most of this period, with a temporary reversal seen at ca. 10,200 yr BP.

Middle Holocene Environments

Variability in $\delta^{13}C$ is lower on canyon slopes and in tributary floodplains between 9,000 and 5,700 yr BP than during the previous period. Although Salmon River floodplain isotopic data are largely absent here, the gradually declining $\delta^{13}C$ compositions noted in tributary floodplains between ca. 8,500 and 6,000 yr BP suggests the same may be happening in the Salmon River floodplain. On average, terminal Pleistocene to early Holocene $\delta^{18}O$ and $\delta^{13}C$ is both higher and lower, respectively, than during the middle Holocene period. This is interpreted as the result of increased solar insolation in July and decreased insolation in January between 11,000 - 9,000 yr BP, as compared to 9,000 - 5,000 yr BP (Berger 1978). Thus, we agree with Elias (1996) who, on the basis of fossil beetle assemblages in the Rocky Mountains region, finds evidence of a thermal maximum during the terminal Pleistocene to early Holocene period instead of during the middle Holocene as originally described by Antevs (1948).

Late Holocene Environments

After 5,000 yr BP, $\delta^{13}C$ values fall in tributary floodplain deposits, showing a reduction in the percentage of C_4 flora, which tracks closely with $\delta^{13}C$ from the Salmon River floodplain between 3,000 and 2,000 yr BP. This pattern is paralleled by declining $\delta^{18}O$ compositions, suggesting the growing presence of cooler and wetter climatic conditions. By the end of the record at 2,000 yr BP, $\delta^{18}O$ values are at their lowest since the terminal Pleistocene. A sharp rise in $\delta^{13}C$ at 10IH1220 is related to the incision of the Salmon River channel into its floodplain, which lowered the water table, favoring drought-resistant C_4 plants.

Conclusions

Stable isotopic compositions in soil carbonates and grain size frequencies in aeolian sediments are interpreted here to reflect regional and local changes in late Pleistocene to Holocene climate conditions, and vegetative populations of riparian and slope areas of the LSRC. The approaches used in this study offer a means of inferring paleoenvironmental conditions from lesser-known lowland Plateau contexts. This study also showed the operation of highly-variable climate conditions across the late Pleistocene to early Holocene (cf. Taylor et al. 1993), and an asynchronous vegetation-climate relationship in canyon riparian zones, which reflect an important degree of late Quaternary ecosystemic complexity. The construction of high resolution records of paleovegetation and paleoclimate from locally-available proxy sources has direct applications in archaeological, geoarchaeological and paleoenvironmental studies of semi-arid and arid locales in the Far West. At this time, studies of this kind are rare at detailed late Pleistocene to Holocene temporal scales.

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CHAPTER FIVE

A LATE PLEISTOCENE TO HOLOCENE RECORD OF PRECIPITATION REFLECTED IN *Margaritifera falcata* SHELL δ^{18}O FROM THREE ARCHAEOLOGICAL SITES IN THE LOWER SALMON RIVER CANYON, IDAHO

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Introduction

Shells of freshwater bivalves are a common occurrence in archaeological sites located along rivers, having been an important food resource for many societies. In the Pacific Northwest three mollusc taxa, *Margaritifera falcata*, *Gonidea angulata* and *Anodonta sp.* typically dominate the bivalve assemblage of sites. Stable isotope geochemistry of molluscs, which is used extensively in geological and paleoenvironmental studies (Kerr-Lawson et al. 1992; Krantz et al. 1987; Jones et al. 1983; Romanek and Grossman 1989; Wefer and Berger 1991), was employed in archaeological studies in marine settings (Baily et al. 1983; Emiliani et al. 1964; Glassow et al. 1994; Herz 1990; Kennett et al. 1997; Killingley 1981; Killingley and Berger 1979; Koerper et al. 1985). Archaeological studies of freshwater bivalve shell stable isotope geochemistry are less common, however (e.g., Kennett and Voorhies 1995). The first part of this paper discusses the theoretical and methodological bases for employing the stable isotope geochemistry of freshwater bivalve shells in archaeological research. This discussion is followed by a presentation of a late Quaternary $\delta^{18}O$ record from *M. falcata* shell carbonate constructed from faunal collections in three archaeological sites in the Lower Salmon River Canyon of Idaho.

In this isotope record, greater aridity is seen in the late Pleistocene and early Holocene, while after ca. 4,000 yr BP precipitation rates are higher than today, continuing on toward modern conditions in the late Holocene. Comparisons made between the Lower Salmon River shell $\delta^{18}O$ record and regional paleoenvironmental records supports the use of this geochemical method to investigate paleoclimate patterns. Taken further, the $\delta^{18}O$ record of Salmon River mussel shell carbonate can be used to help interpret paleoenvironmental aspects influenced by rainfall regimes such as processes of soil formation, vegetation patterns, and conditions of faunal habitats and to evaluate the ecological context of prehistoric hunter-gatherer adaptations.

Research with Freshwater Bivalves

Two major methodological approaches are present in paleoenvironmental studies of river mussels in North American archaeology. The first involves studies of species occurrence in archaeological sites, while the other addresses processes of shell production. Both studies aim to interpret aspects of invertebrate faunal assemblages in terms of their specific autecological requirements as a means of establishing proxy records of paleoenvironmental conditions.

In the first approach, aquatic conditions are inferred from the relative abundance of certain mussel species found in an archaeological assemblage. Differences in species abundance are interpreted to indicate the effects of climatic conditions on their habitats, as one species increases its population over the other under conditions that favor its autecological requirements (Landye 1973; Chatters 1986; Chatters et al. 1991, 1995).

The usefulness of this method was questioned by Lyman (1980:127), who cautions that while the two species have different microenvironmental requirements, they can both be found within a linear kilometer of river in some areas. As well, since the presence of bivalve shells in archaeological sites is typically seen as the result of subsistence gathering activities in these studies, the level to which shell assemblages represent natural conditions, and not a culturally-biased sample, is unclear. For these reasons, the results of river mussel species abundance studies appear to provide ambiguous statements about climatic or hydrological conditions of the past.

The second approach is represented by the work of Chatters et al. (1995), who reconstruct ancient stream environments in the Wells Reservoir region of the Columbia River Basin of northern Washington. Annual stream temperatures are inferred through an investigation of the relationship between modern river bivalve growth and water temperatures, which is based on an unpublished study (Chatters et al. 1995:491). Chatters claims to have discovered a linear function between the number of days where water temperatures are between 6-10° C and the thickness of modern mussel shell growth bands. Since a comprehensive report on this method and its relationship to ambient Columbia River conditions is not available for review, and given the uncertainties of whether growth patterns among modern mussel populations in a hydroelectric dam reservoir provides a "natural" perspective on mollusc growth response to habitat conditions, it may be premature to use this approach as a way to derive paleothermometry data. A more appropriate method of this kind would involve a study of mussels in a natural habitat, such as a free-flowing stream largely unaffected by human activities, or in a controlled laboratory setting.

Stable Isotope Geochemistry of Freshwater Bivalves

The application of stable isotope geochemistry to freshwater bivalves has mainly been used to infer lacustrine hydrology (Kerr-Lawson et al. 1992; Hodell et al. 1991, 1995), although studies of riverine molluscs are available (e.g., Dettman and Lohmann 1993). The isotopic signature of shell carbonates in freshwater invertebrates reflects the isotopic composition of ambient environmental water (Fritz and Poplawski 1974; Kerr-Lawson et al. 1992; Dettman and Lohman 1993).

Two models are available to interpret the $\delta^{18}O$ signature of riverine bivalve shell carbonate. Dettman and Lohmann (1993) define these models as "temperature-dominated" and "water-based." In the first model, variability in shell $\delta^{18}O$ is a reflection of changes in surface water temperature. In fluvial systems dominated by groundwater input, variation in the isotopic composition of meteoric water at seasonal scales is overwhelmed by the isotopic effects of seasonal changes in water temperature.

Under a "water-based" model, the effects of temperature-dependent $\delta^{18}O$ fractionation is greatly diminished relative to seasonal changes in the $\delta^{18}O$ of precipitation. Of greater importance is the influence of regional climate on the isotopic composition of meteoric water. Changes in the $^{18}O/^{16}O$ ratio in river water are driven by variations in the isotopic character of meteoric water, produced as atmospheric water vapor moves inland from its oceanic source (Craig 1961; Dansgaard 1964) (Figure 87). Thus, in a "water-based" model, isotopic changes in meteoric precipitation reflect variability in "the condensation of atmospheric water vapor, at the prevailing air temperature, with isotopic equilibrium maintained between vapour and condensate" (Welhan 1987:134). Unlike the first model, $\delta^{18}O$ data interpreted through the "water-based" model can be viewed as a proxy record of regional precipitation regimes.

A Model of Salmon River Bivalve Shell Geochemistry

The fluvial behavior of the Salmon River is typical of other Columbia River basin streams, in that the pattern of annual discharge is determined by the timing and rate of runoff from melting snowpack in the upper reaches of the basin. Inputs of water from rainfall events produce only minor alterations to river flow and rates of discharge closely follow the melting of the snowpack (Paulsen 1949). This pattern of discharge strongly suggests that the hydrology of the Salmon River is not dominated by groundwater

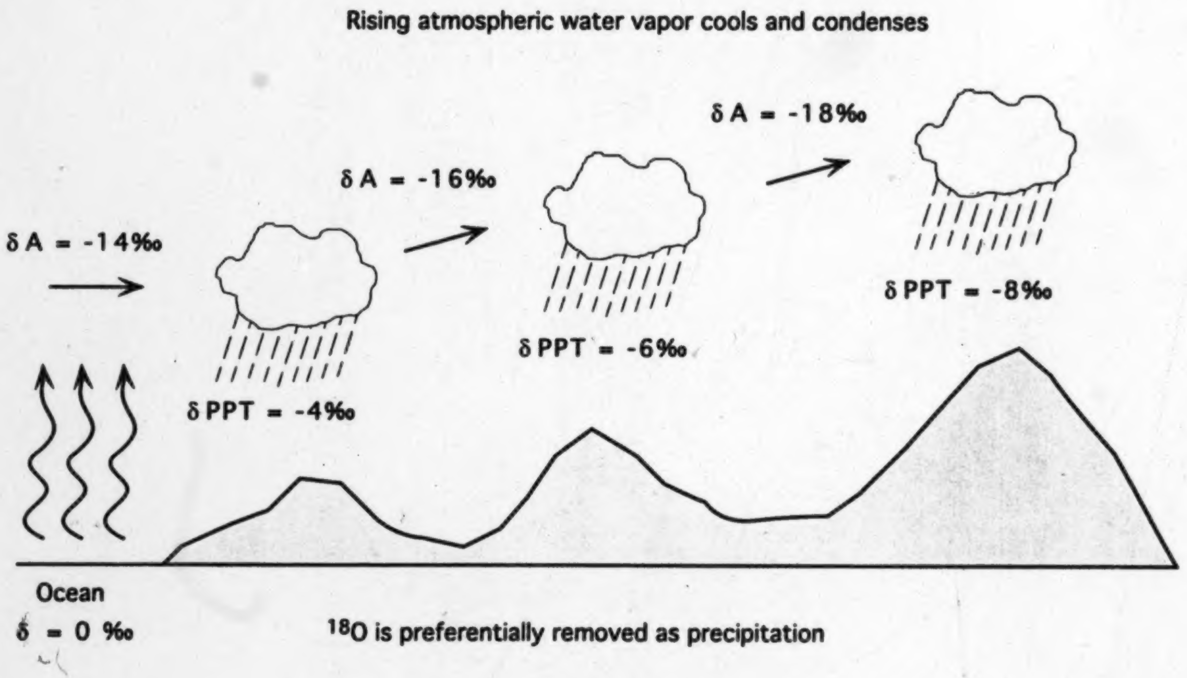
Rising atmospheric water vapor cools and condenses
δ A = -14‰
δ A = -16‰
δ A = -18‰
δ PPT = -4‰
δ PPT = -6‰
δ PPT = -8‰
Ocean
δ = 0 ‰
18O is preferentially removed as precipitation

Figure 87. Isotopic changes in atmospheric water vapor (δA) and preferential rainout of ^{18}O-enriched water (δPPT) with inland movement from oceanic sources (adapted from Welhan 1987).

inputs. Since the reservoir of water that makes up the Salmon River discharge largely comes from atmospheric precipitation accumulated in the snowpack, it is expected that the $\delta^{18}O$ signature of freshwater bivalve shell carbonate will mirror changes in regional climatic effects on meteoric water and not from temperature effects on groundwater inputs.

Given these considerations, periods of heightened aridity are expected to produce an increase in the composition of $\delta^{18}O$ in meteoric water, which is also reflected in mussel shell carbonate geochemistry (Figure 88). During periods of increased precipitation, the $\delta^{18}O$ signature of meteoric water will become more negative, producing similar trends in the $\delta^{18}O$ of freshwater bivalve shells.

By using the $\delta^{18}O$ signature of modern riverine bivalve shells as an isotopic baseline, comparisons can be made with the $\delta^{18}O$ of bivalve shells from archaeological sites to provide a means of evaluating isotopic changes in the regional meteoric water that entered the basin. This record can be considered to represent a proxy for paleoprecipitation regimes, with changes in the $\delta^{18}O$ signature of shells interpreted as representing variability in regional climates. We assume little to no diagenetic effects from soil water altered shell geochemistry, as shell samples were collected from buried contexts beyond the limits of soil wetting depth in the local semi-arid environment.

Methods

Modern *M. falcata* shells were collected from active flood zones in several locations along the Lower Salmon River. Fossil samples of *M. falcata* shell were obtained from faunal collections of three archaeological sites excavated along the Lower Salmon River. Shell samples were submitted for x-ray diffraction and revealed an aragonite mineralogy. All shell carbonate samples were initially bleached with NaOCl(aq) and oven dried. Bulk carbonate samples representing homogenized portions of entire shells were individually reacted *in vacuo* at 25.3°C with H_3PO_4. The evolved CO_2 gas was cryogenically isolated and analyzed with a Finnigan MAT 252 mass spectrometer, which has an internal error of ±0.1‰ for carbonates. $\delta^{18}O$ and $\delta^{13}C$ signatures are compared to standard mean ocean water (SMOW) (Baertschi 1976) and Peedee Belemenite (PDB) (Craig 1957), respectively; all results are reported in parts per mil (‰).

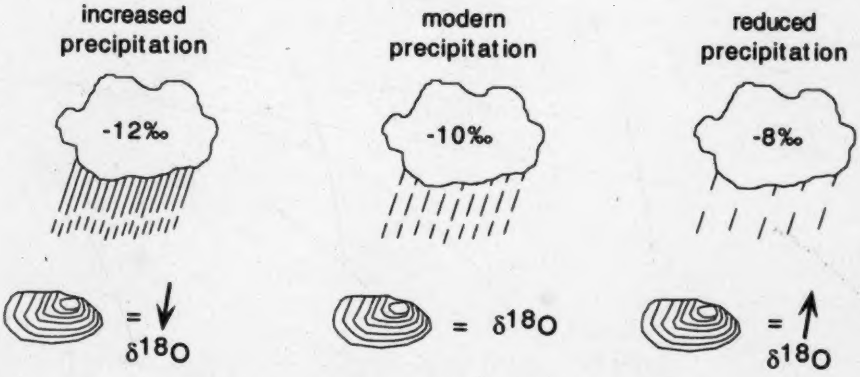
increased precipitation
-12‰
= ↓ δ18O
modern precipitation
-10‰
= δ18O
reduced precipitation
-8‰
= ↑ δ18O

Figure 88. Expected trends in $\delta^{18}O$ of freshwater mussel shell carbonate formed under differing precipitation regimes.

Context of the Study Area

The Salmon River originates in the mountains of central and eastern Idaho in the Pacific Northwest of the United States (Figure 89). Melting winter snowpack and rainfall during the spring months produces a pronounced increase in annual fluvial discharge. Temperatures and precipitation vary with elevation, with reduced rainfall and greater aridity in the lowland canyons and mesic conditions in the uplands and mountains. Climatological data for several localities in and around the Salmon River basin are presented in Table 8.

Vannote and Minshall (1982) reported the modern distribution of *M. falcata* in the Salmon River. They note that the best-developed river mussel communities are found in those areas with large stable cobble and boulder channel gravels. Since most of the Lower Salmon River flows over a bedload comprised of coarse clastic material, *M. falcata* locally dominates the genera of river mussels found in local archaeological sites (Drake 1963; L.G. Davis, unpublished data).

M. falcata shells from three archaeological sites located along the Lower Salmon River were used in this study (Figure 89). To place the samples in a stratigraphic and temporal context, a brief review will be provided of the site stratigraphy.

The Cooper's Ferry site (10IH73) produced *M. falcata* shells associated with cultural occupation in stratified aeolian and alluvial sediments. Two radiocarbon dates from the Cooper's Ferry site were used in this study: 11,410 yr BP and 8,430 yr BP (Table 9). Although other radiocarbon dates were produced from the Cooper's Ferry site, only a selected number are used to build a temporal framework for this study due to issues of possible contamination of bone collagen dates and vertical displacement of charcoal samples in rodent burrows. The stratigraphic record of this site and the positions of radiocarbon dates used in this study are shown in Figure 90c.

The Gill Gulch site (10IH1308) was excavated by the Bureau of Land Management (BLM) and produced evidence of later Holocene cultural occupation on an aggrading alluvial fan surface (Dickerson 1997). Shells were collected from two test excavation units (Figure 90b and 90d), which produced radiocarbon ages between 4,940 and 3,340 yr BP (Table 9).

Station	Ann. T	TDJF	TMAM	TJJA	TSON	Ann. P	PDJF	PMAM	PJJA	PSON
Cottonwood	13.2	2.6	12.4	24.3	13.6	56.9	12.7	18.3	13.5	12.5
Lewiston	17.4	5.5	16.9	29.7	17.3	32.5	8.4	9.7	7.1	7.6
Boise	17.2	4.4	16.7	30.2	17.7	30.2	10.2	9.4	3.8	7.1
Nezperce	13.8	2.8	12.8	25.3	14.2	53.9	11.9	17.5	11.7	12.7
Grangeville	8.0	-0.7	7.0	17.5	8.2	60.7	11.2	21.6	13.7	14.2
Riggins	19.2	6.9	18.8	31.7	19.3	42.7	9.4	14.2	9.1	10.2

Table 8. Climatological data from selected stations in and around the Salmon River basin, Idaho (Western Regional Climate Center 1999). Annual (Ann.) and seasonal (DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November) Temperature (T) shown in degrees C. Annual and seasonal precipitation (P) shown in centimeters.

Site	Depth (cm BD)	Material	Lab number*	Age (RCYBP)†
10IH1312	25	wood charcoal	TO-7350[1]	1,140 ±60
10IH1312	35	wood charcoal	TO-7354[1]	1,680 ±60
10IH1312	39	wood charcoal	TO-7355[1]	1,780 ±50
10IH1308/1	40-50	mussel shell	Tx-9271[2]	3,340 ±60
10IH1308/2	80-90	mussel shell	Tx-9272[2]	3,690 ±50
10IH1308/1	80-90	mussel shell	Tx-9373[2]	3,840 ±50
10IH1308/2	90-100	bone collagen	Beta-11657[1]	4,780 ±100
10IH1308/2	120-130	mussel shell	Tx-9275[2]	4,940 ±100
10IH73	75	wood charcoal	Beta-114952[1]	8,430 ±70
10IH73	180	wood charcoal	TO-7349[1]	11,410 ±130

Table 9. Radiocarbon dates from Lower Salmon River Canyon archaeological sites used in this study. Depth is reported in centimeters below datum; *Beta refers to Beta Analytic, TO refers to Isotrace Radiocarbon Laboratory, University of Toronto, Tx refers to University of Texas, Austin ([1]AMS date, [2]conventional radiocarbon date); †uncalibrated ^{14}C age in radiocarbon years before present.

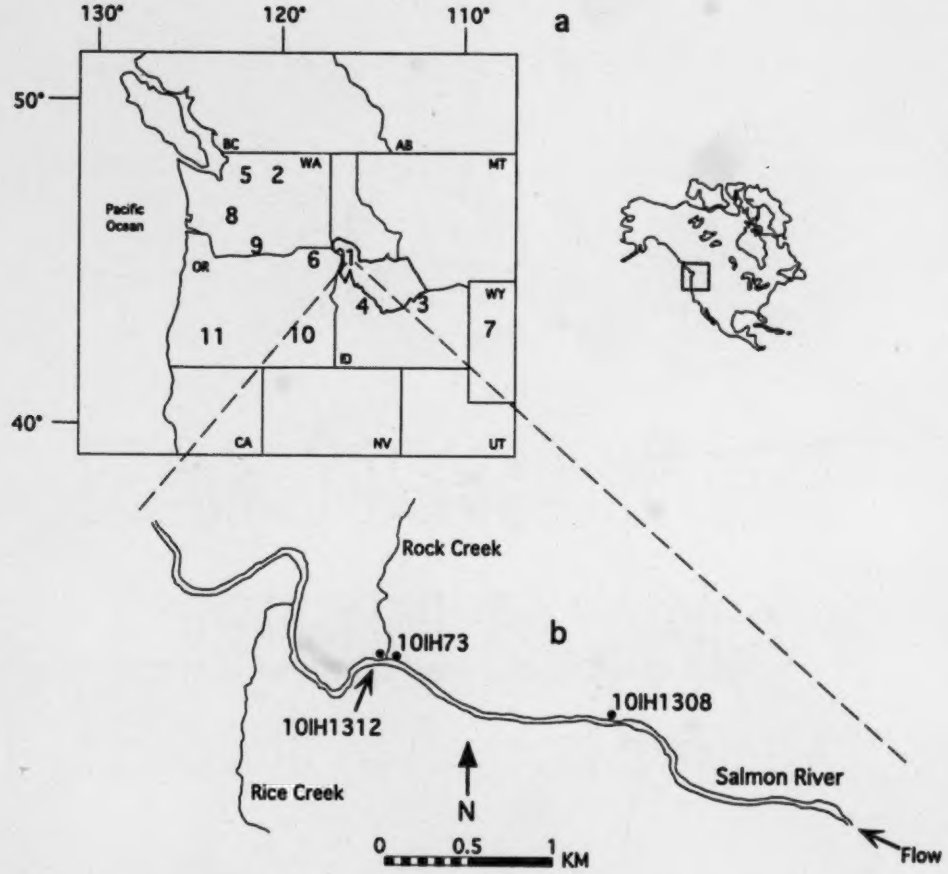
a
130°
120°
110°
50°
40°
BC
AB
WA
MT
Pacific Ocean
OR
WY
ID
CA
NV
UT
5
2
8
9
6
1
4
3
7
11
10
b
Rock Creek
10IH73
10IH1312
10IH1308
Rice Creek
Salmon River
N
0
0.5
1
KM
Flow

Figure 89. Map of study area showing (a) location of the Salmon River basin in relation to regional paleoenvironmental sites discussed in text: 1, Lower Salmon River Canyon study area and Salmon River basin (shaded portion); 2, Wells Reservoir; 3, Lemhi Mountain Range; 4, Pioneer Mountain Range; 5, Glacier Peak; 6, Wallowa Mountains; 7, Wind River Range; 8, Mount Rainier; 9, Carp Lake; 10, Diamond pond; 11, Mount Mazama (Crater Lake). Exploded map at bottom (b) shows Lower Salmon River Canyon study area with position of archaeological sites used in this study.

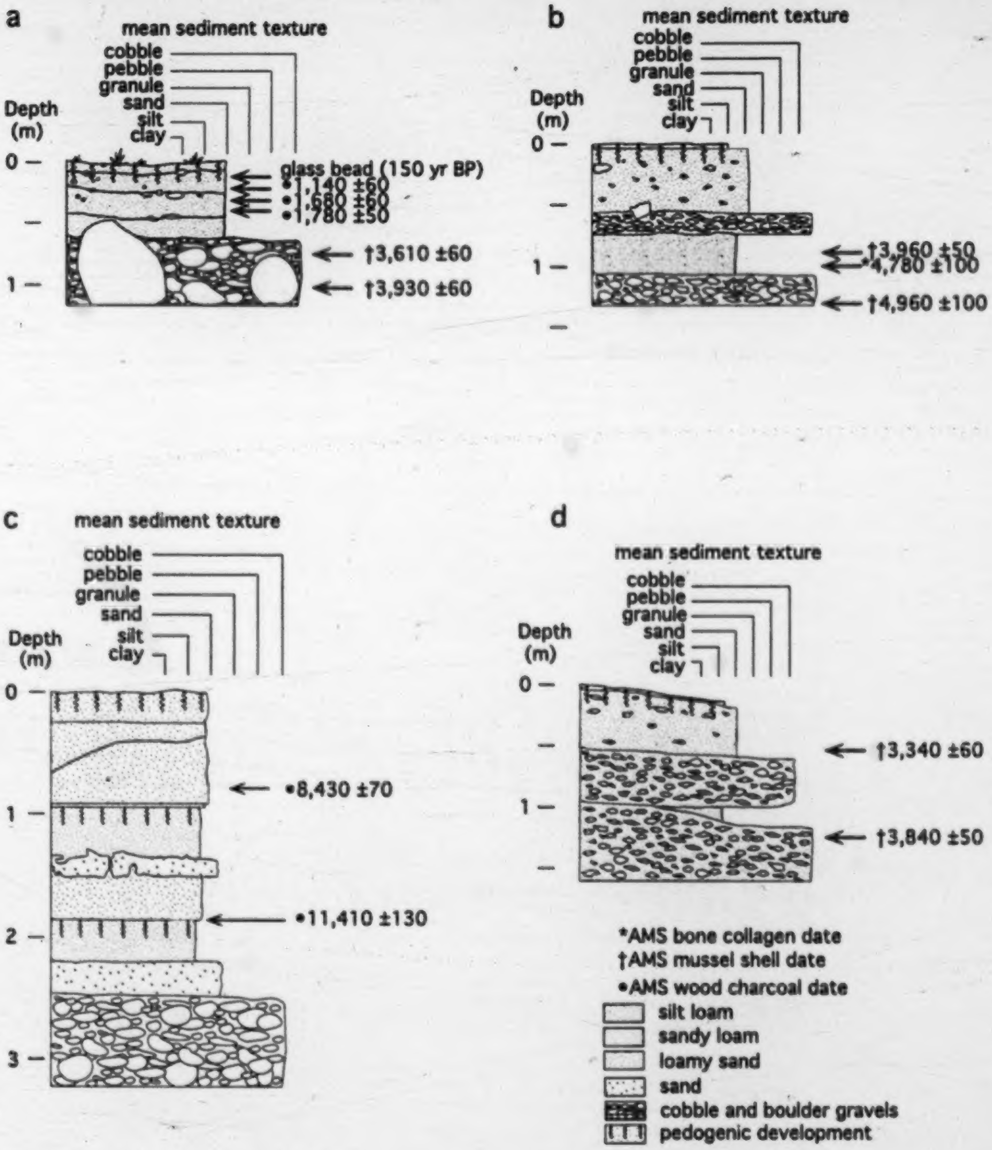
a
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
glass bead (150 yr BP)
•1,140 ±60
•1,680 ±60
•1,780 ±50
†3,610 ±60
†3,930 ±60
b
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
†3,960 ±50
*4,780 ±100
†4,960 ±100
c
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
•8,430 ±70
•11,410 ±130
d
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
†3,340 ±60
†3,840 ±50
*AMS bone collagen date
†AMS mussel shell date
•AMS wood charcoal date
silt loam
sandy loam
loamy sand
sand
cobble and boulder gravels
pedogenic development

Figure 90. Stratigraphic profiles from the Nipehéme Village site (10IH1312) Unit A and B composite (a), the Gill Gulch site (10IH1308) Unit 2 (b), the Cooper's Ferry site (10IH73) Unit A (c), and the Gill Gulch site (10IH1308) Unit 1 (d) showing positions of lithostratigraphic units, pedostratigraphic units and radiocarbon dates relative to depth in meters. Radiocarbon dates shown are in uncalibrated ^{14}C years BP. Stratigraphic profiles from the Gill Gulch site are based on descriptions made by Dickerson (1997).

The last site included in this study is the Nipeheme Village site (10IH1312), where shells were associated with intensive cultural occupation on a floodplain (Figure 90a) with radiocarbon dates ranging between 1,780 and 1,140 yr BP (Table 9). Relative age markers are provided in the upper portion of the site by the presence of protohistoric artifacts, including a glass trade bead. The protohistoric period in west-central Idaho is considered to fall between ca. 450 yr BP and ca. 150 yr BP (A.D. 1500 to 1805) (Sappington 1994:337). At the Nipeheme Village site, a terminal protohistoric date of 150 yr BP is placed on the context of the glass bead.

Establishing a Temporal Scale

The stratigraphic position of radiocarbon ages and protohistoric artifacts in the three sites were used to establish a temporal scale for mussel shell geochemistry. The isotopic results of shell samples were organized as a time series by normalizing rates of deposition between the position of radiocarbon ages.

Presentation of Data

The results of isotopic analyses on river mussel shell carbonates from modern and archaeological samples are presented in Table 10. Modern *M. falcata* shells returned $\delta^{18}O$ values near 13.6‰, while $\delta^{13}C$ values were more variable. Shell $\delta^{18}O$ values ranged from 12.6‰ to 15.3‰ in all archaeological samples, with a mean of 13.5‰ and a standard deviation of 0.5‰. The $\delta^{13}C$ values of archaeological shells spanned -2.9‰ to -7.5‰, averaging -5.2‰ with a standard deviation of -1.0‰. Comparisons between archaeological shell $\delta^{18}O$ and $\delta^{13}C$ fail to reflect a strong correlation in all cases (Figure 91).

Interpretation

Modern *M. falcata* shell $\delta^{18}O$ is used as a baseline value (13.6‰) for comparison with the isotopic composition of archaeological shell samples (Figure 92). $\delta^{18}O$ values exceeding 13.6‰ reflect lower atmospheric precipitation rates relative to modern climate conditions while $\delta^{18}O$ values lower than the baseline reflect periods of increased atmospheric precipitation. Mussel shell $\delta^{13}C$ reflects the dissolved carbon present in the river water during shell construction (Kerr-Lawson et al. 1992). As the origin of this

Site	Depth (cm bd)	$\delta^{18}O_{SMOW}$‰	$\delta^{13}C_{PDB}$‰
Pine Bar 1	surface	13.6	-8.1
Pine Bar 2	surface	13.6	-8.3
Apricot Bar	surface	13.5	-9.3
10IH1312	15	13.5	-4.1
10IH1312	25.5	13.4	-3.9
10IH1312	26	13.6	-5.7
10IH1312	29	13.4	-5.3
10IH1312	32	13.5	-4.3
10IH1312	35	12.6	-7.5
10IH1312	39	13.7	-4.3
10IH1312	45	13.6	-5.5
10IH1312	55	13.3	-6.1
10IH1312	65	13.7	-5.6
10IH1312	75	13.4	-5.1
10IH1312	85	13.3	-5.3
10IH1308/1	15	13.0	-3.8
10IH1308/1	25	13.1	-5.5
10IH1308/1	35	13.1	-5.1
10IH1308/1	65	13.2	-5.8
10IH1308/1	85	12.8	-5.6
10IH1308/1	95	13.1	-5.7
10IH1308/1	105	14.7	-5.9
10IH1308/1	125	14.2	-6.9
10IH1308/1	135	12.7	-7.2
10IH1308/1	155	12.8	-5.3
10IH1308/2	15	13.6	-4.1
10IH1308/2	25	13.6	-4.7
10IH1308/2	35	13.4	-4.7
10IH1308/2	45	13.7	-3.2
10IH1308/2	65	13.5	-4.7
10IH1308/2	75	13.2	-5.0
10IH1308/2	85	13.3	-4.2
10IH1308/2	115	13.3	-3.4
10IH1308/2	135	13.0	-5.5
10IH73	40	13.3	-5.6
10IH73	50	13.8	-6.1
10IH73	80	13.1	-5.1
10IH73	90	14.0	-5.2
10IH73	110	13.5	-5.2
10IH73	120	13.8	-5.6
10IH73	130	15.3	-2.9
10IH73	160	14.3	-6.6
10IH73	170	13.2	-5.4
10IH73	180	14.4	-3.9
10IH73	190	13.3	-5.4

Table 10. Stable isotope geochemistry data from *M. falcata* shells collected at Lower Salmon River Canyon beaches and archaeological sites-10IH73, 10IH1308 units 1 and 2, and 10IH1312: depth is reported in centimeters below datum.

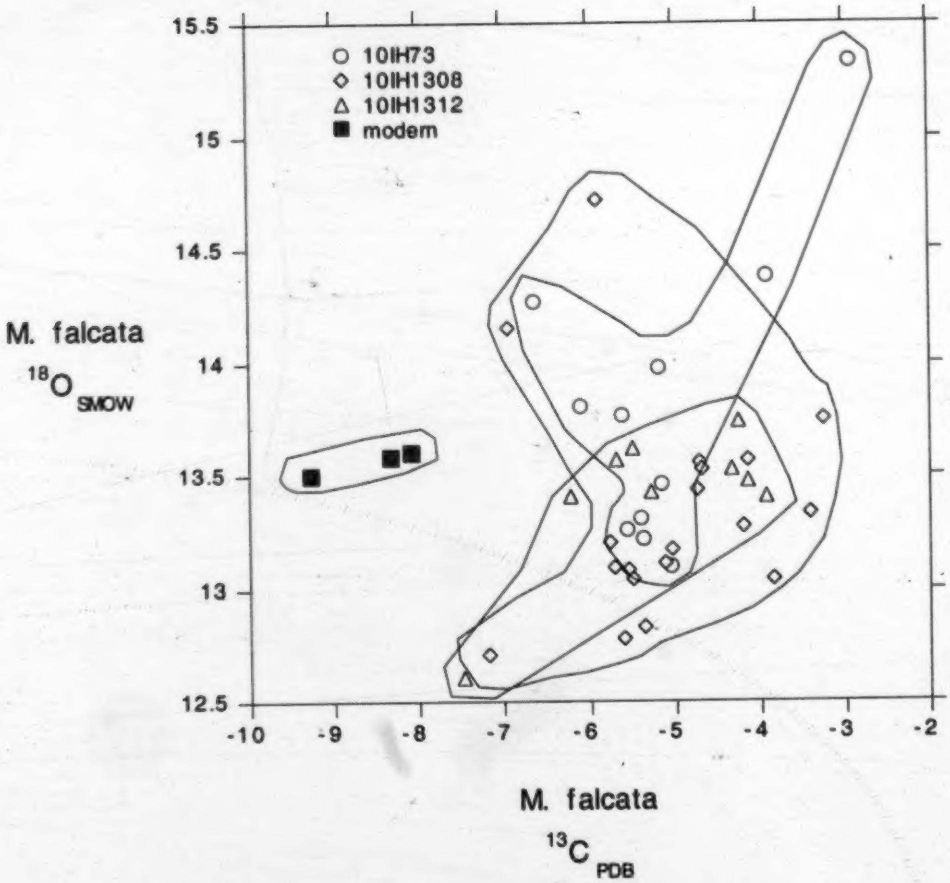

Figure 91. Cross plot of $\delta^{18}O$ vs. $\delta^{13}C$ from *M. falcata* shell samples in Lower Salmon River Canyon archaeological sites; samples from the Cooper's Ferry site (10IH73) shown as open triangles; samples from the Gill Gulch site (10IH1308) presented as open diamonds; samples from the Nipeheme Village site (10IH1312) shown here as open circles; samples from modern beaches shown as closed boxes. Patterns of regression lines for site data shown above cross plot correspond to line patterns shown in key.

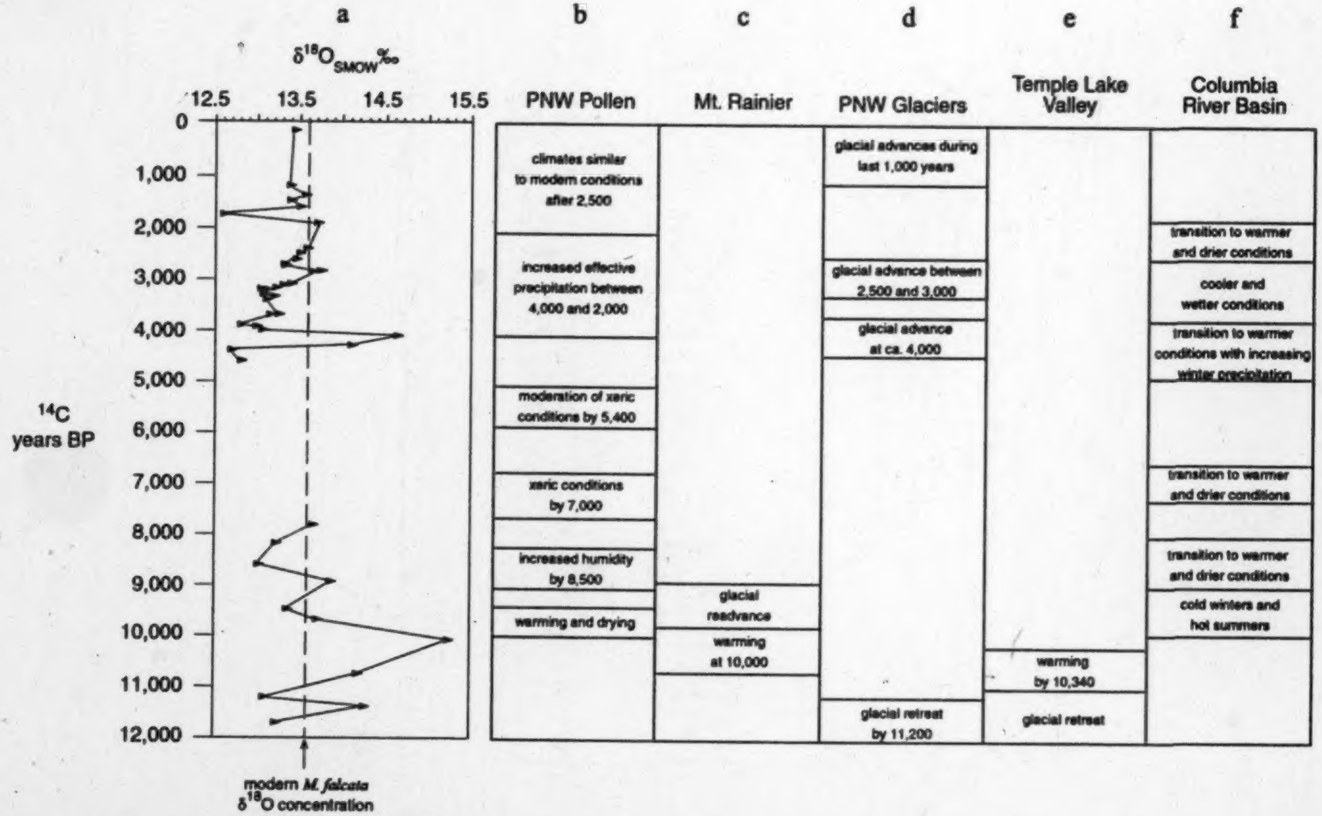

Figure 92. Comparison of Lower Salmon River Canyon M. falcata $\delta^{18}O$ record with regional paleoenvironmental proxy records. Composite record of $\delta^{18}O$ values reported from each site (see Table 10) are plotted against an interpolated time curve presented in uncorrected radiocarbon years BP (a); $\delta^{18}O$ values from archaeological sites are projected relative to the modern M. falcata shell $\delta^{18}O$ signature, shown as a vertical dashed line. Summarized paleoenvironmental conditions derived from Pacific Northwest pollen (b), Mt. Rainier (c), Pacific Northwest glaciers (d), Temple Lake Valley glaciers (e), and Columbia River basin proxy conditions (f) follow aforementioned sources in text.

carbon can be attributed to many sources (e.g., C_3 and C_4 plant matter, carbon-bearing bedrock) in the basin, the overall meaning can be obscure. This consideration helps to explain the poor fitness between shell $\delta^{18}O$ and $\delta^{13}C$ compositions shown in Figure 91. Because of the ambiguity between $\delta^{13}C$ and $\delta^{18}O$ variability in Lower Salmon River *M. falcata* shells, the carbon-13 signature is not considered to clearly represent paleoenvironmental conditions.

During the late Pleistocene and early Holocene, $\delta^{18}O$ values in *M. falcata* shells fluctuate relative to modern mussels, indicating that late Pleistocene and early Holocene precipitation in the Salmon River basin was not stable. Three notable periods of aridity are seen, with the first at 11,400 yr BP and the second event rising after 11,000 yr BP, culminating immediately before 10,000 yr BP and the third at 9,000 yr BP. During the first arid period, $\delta^{18}O$ compositions shift from 13.3‰ to 14.4‰ between ca. 11,800 to 11,500 yr BP. Between ca. 11,200 to 10,100 yr BP, $\delta^{18}O$ values vary between 13.2‰ and 15.3‰, marking the driest period in the past 12,000 yr BP. A change to arid conditions is seen again between ca. 9,500 and 9,000 yr BP, represented by a change in $\delta^{18}O$ from 13.5‰ to 14.0‰. Lastly, precipitation decreases between ca. 8,600 to 8,100 yr BP, marked by an increase in $\delta^{18}O$ composition from 13.1‰ to 13.8‰. Early trends toward wetter conditions are seen at 11,700 yr BP (13.3‰), from 11,500 to 11,200 yr BP with an $\delta^{18}O$ change from 14.4‰ to 13.2‰, between ca. 10,000 to 9,500 yr BP associated with a shift from 15.3‰ to 13.5‰, and from ca. 9,000 to 8,600 yr BP, where $\delta^{18}O$ values change from 14.0‰ to 13.1‰.

Between ca. 4,500 and 4,100 yr BP, $\delta^{18}O$ values change from 12.7‰ to 14.7‰, reflecting a rapid and major shift to arid conditions. This trend is quickly reversed by a return to wet conditions between 4,100 and ca. 3,950 yr BP marked by a change in $\delta^{18}O$ from 14.7‰ to 13.1‰. From ca. 4,000 and 2,950 yr BP $\delta^{18}O$ values fall between 13.1‰ and 13.7‰, showing the presence of wetter conditions that gradually decrease through time. After a sharp but short decrease in $\delta^{18}O$ composition to 13.3‰ after ca. 2,950 yr BP, which is interpreted as a brief return of wetter climates, values increase under conditions of decreasing precipitation to 13.7‰ by ca. 1,950 yr BP. Another abrupt shift toward increased rainfall is seen at ca. 1,800 yr BP with $\delta^{18}O$ values at 12.6‰, the lowest of the entire record. By ca. 1,700 yr BP, precipitation is much reduced, with $\delta^{18}O$ compositions at 13.5‰. After ca. 1,700 yr BP, rainfall appears close to modern conditions.

Carbon-13 values of mussel shell carbonates are interpreted to reflect the nature of inorganic carbon dissolved in river or stream water during shell formation (Kerr-Lawson et al. 1992). A lack of agreement between trends of shell $\delta^{18}O$ and $\delta^{13}C$ is expected in riverine bivalves, since much of the dissolved carbon may come from plants that grow in different habitats throughout the basin.

Since the Salmon River basin is large in area and contains a diverse plant population, the distribution of which is largely controlled by elevation effects on temperature, precipitation and evaporation, different $\delta^{13}C$ values are expected among shells that live in the main Salmon River water as compared to lowland tributary basin stream water. While the $\delta^{18}O$ of the water from both of these basins is expected to be the same under a water-based model of isotope geochemistry the plant populations in each will be different and are expected to produce different $\delta^{13}C$ values in their waters.

Comparisons with Regional Paleoclimatic Records

Records of late Pleistocene to Holocene paleoclimatic conditions are available from several areas in the Pacific Northwest. These records are derived from pollen and organic carbon deposition in lakes and bogs, and fluvial geomorphology histories reflected in depositional and erosional events in fluvial basins. Histories of glacial advances are present in Pacific Northwest mountain ranges and the Rocky Mountains from the Wind River Range of Wyoming, as synthesized by P.T. Davis (1988). Paleoclimatic records summarized in the sections below are compared against the Lower Salmon River Canyon *M. falcata* shell $\delta^{18}O$ record in Figure 92.

Late Pleistocene and Early Holocene

Butler (1984a, 1984b, 1986) marks the timing of late Wisconsinan deglaciation of east-central Idaho's Lemhi Range prior to 11,200 due to the presence of Glacier Peak set B tephra in alpine meadow sediments. Cotter et al. (1986) also place late Wisconsinan glacial retreat in the Pioneer Mountains of central Idaho by at least 11,200 yr BP based on the presence of Glacier Peak set B tephra within bog sediments deposited in a kettle hole feature. Butler (1984a, 1986) reports periglacial wedges and deformed bedding structures dating between 10,130 yr BP and 7,560 yr BP, which are interpreted as bracketing a return of cold conditions.

At Glacier Peak, in the northern Cascade Range of Washington, the distribution of the Glacier Peak set B tephra points to the local retreat of glaciers before 11,200 yr BP (Porter 1978). Increased organic sedimentation in alpine lakes on Mt. Rainier at 10,000 yr BP is interpreted as evidence of early Holocene climatic warming (Heine 1998).

Zielinski (1987) and Zielinski and Davis (1987) date the rapid retreat of glacial ice in the Temple Lake valley between ca. 11,000 yr BP and 12,000 yr BP on the basis of radiocarbon-dated organic material from Temple Lake and Rapid Lake cores (P.T. Davis 1988). Warmer conditions are seen to prevail in the Temple Lake valley by 10,340 yr BP and 11,370 yr BP, as reflected in an increase in organic sedimentation in lakes and between moraines (P.T. Davis 1988).

Pollen records point to warmer and drier conditions in the Pacific Northwest between 10,000 - 9,500 yr BP (Sea and Whitlock 1995), while general post-glacial warming is observed throughout most of the Pacific Northwest by 10,000 yr BP (Mehringer 1985). Between 9,800 and 8,950 yr BP, glaciers readvance on Mt. Rainier, suggesting a return to cooler and wetter conditions (Heine 1998). Barnosky (1985) reports a shift towards increased humidity at ca. 8,500 yr BP, interpreted from increasing pine pollen at Carp Lake in south-central Washington. Kiver (1974) identified a period of advance for the Glacier Lake moraine in the Wallowa Mountains of northeastern Oregon between ca. 9,000 yr BP and before the eruption of the Mazama set O tephra at 6,800 yr BP (Bacon 1983). Confirmation of this general scheme comes from rates of boulder weathering and pedostratigraphic data provided by Burke (1978). Mehringer (1985) notes that inland Pacific Northwest pollen records show decreased effective moisture and warm conditions by 7,000 yr BP, resulting in the desiccation of lakes in some lower elevations areas.

Chatters and Hoover (1992) report alluvial aggradation events on the middle Columbia River of eastern Washington between 9,000 - 8,000 yr BP, 7,000 - 6,500 yr BP, 4,400 - 3,900 yr BP, and 2,400 - 1,800 yr BP. The timing of these aggradation periods are attributed to transitions from cold, moist climate conditions to drier, warmer conditions (Chatters and Hoover 1992:54). Drawing upon a number of proxy paleoclimate sources (Chatters 1991), Chatters and Hoover (1992) infer paleoclimatic conditions for several early Holocene periods: cold winters and hot summers with a possibility of spring precipitation is posited for the period 10,000 - 9,000 yr BP, while climates change to warmer winters and hot summers with winter-dominant precipitation between 9,000 - 8,000 yr BP.

Middle to Late Holocene

Paleoenvironmental records show a general trend toward cooler and wetter conditions during this period. Earlier xeric conditions apparently became more moderate by 5,400 yr BP throughout much of the region and changed to wetter, cooler conditions with increased effective precipitation by 4,000 yr BP (Mehringer 1985). Neoglacial readvances are posited at ca. 4,000 yr BP and within the last 1,000 years in the Lemhi Range (Knoll 1977; Butler 1984b, 1986) and Lost River Range (Cluer 1987) of Idaho on the basis of relative ages on glacial features. Three late Holocene glacial advances are seen in the Wallowa Mountains, with events dated to between ca. 2,500 yr BP and 3,000 yr BP, at ca. 1,000 yr BP and within the last 500 yr BP on the basis of the tephrostratigraphy (Kiver 1974), boulder weathering rinds and soil development (Burke 1978). Tephrostratigraphy and dendrochronology are used to date the maximum extent of two glacial advances at Glacier Peak between 5,100 to 5,500 yr BP, at ca. 3,400 and before AD 1650 (Beget, 1984).

On the basis of proxy paleoclimate data synthesized from multiple sources in the Columbia River Basin, Chatters (1991) infers warming winter conditions and hot summers with winter-dominant precipitation between 8,000 - 4,400 yr BP, while a brief shift to cooler and moister conditions possibly occurred between 7,800 - 6,500 yr BP. Wigand's (1987) work at Diamond Pond in southeastern Oregon shows a record of increased effective precipitation between 4,000 - 2,000 yr BP. Increased quantities of mesic plants are seen at Carp Lake after 5,000 yr BP, suggesting climatic amelioration (Barnosky 1985). Cold winter and cool summer conditions with winter-dominant precipitation apparently prevailed in the Columbia Basin between 3,900 - 2,400 yr BP, shifting to warmer winter and summer climates with a reduction in winter-dominant precipitation from 2,400 - 1,800 yr BP (Chatters 1991). Pollen records reflect climatic conditions similar to today after 2,500 yr BP (Mehringer 1985).

Comparisons with Isotopic Record

Patterns of $\delta^{18}O$ composition in *M. falcata* shell carbonate show many similarities with regional paleoclimate records. Retreat of glacial ice in the Wind River Range between 12,000 and 11,000 yr BP may be coincident with increased aridity suggested by shell $\delta^{18}O$. General warming and drying of regional climates by 10,000 yr BP is reflected by increased compositions of $\delta^{18}O$ in Lower Salmon River Canyon shells between ca. 11,000 and 10,000 yr BP. Variability in pollen records during the early Holocene is matched in the isotopic record, particularly at ca. 8,500 yr BP, which is marked by decreased $\delta^{18}O$ values in Lower Salmon River Canyon shells and increased humidity at Carp Lake (Barnosky 1985). Warmer and drier conditions reported from the Columbia River Basin between 9,000 and 8,000 yr BP (Chatters 1991) are seen at ca. 9,000 yr BP in the isotopic record; however, wetter conditions are seen afterwards until ca. 7,900 yr BP. Early Holocene periglacial conditions reported by Butler (1984a, 1986) in the Lemhi Range may be associated with the decrease in shell $\delta^{18}O$ between 9,000 and 8,000 yr BP.

Late Holocene conditions also correlate well between isotope and regional proxy records. Warmer, drier conditions seen in the Columbia River Basin between 4,400 - 3,900 (Chatters 1991) are matched by increased $\delta^{18}O$ values briefly from ca. 4,200 to 4,000 yr BP. Decreased $\delta^{18}O$ compositions after 4,000 yr BP, reflecting increased precipitation rates, compare favorably with a cooler and wetter climate interpreted from Pacific Northwest pollen records and alluvial cycles of the middle Columbia River Basin from the same time period (Mehringer 1985; Chatters 1991). This increase in mesic conditions is also correlated to neoglacial advances in many areas of the Far West. Inland Pacific Northwest pollen records reflect climatic conditions similar to today by ca. 2,500 yr BP, while *M. falcata* shells show near modern $\delta^{18}O$ signatures during this time. The sharp, rapid decline in shell $\delta^{18}O$ at ca. 1,850 yr BP correlates to the end of alluvial aggradation in the middle Columbia River Basin by 1,800 yr BP (Chatters and Hoover 1992), both suggesting a shift to cooler and wetter conditions. Climate conditions associated with renewed activity in regional glaciers during the last millennia is not reflected in the shell $\delta^{18}O$ record, due to its low temporal resolution after ca. 1,100 yr BP.

Comparison with Regional Archaeological Record

Traditionally, paleoenvironmental records are given a great deal of attention by Plateau archaeologists, who value these data as a means of providing a contextual basis for model building in prehistory. While causal comparisons of cultural and environmental records do not necessarily explain the cultural behaviors themselves, they are an important starting point for developing research questions in regional archaeology. Here, brief comparisons are made between southern Plateau archaeological records and the *M. falcata* shell $\delta^{18}O$ record of the Lower Salmon River Canyon in order to illustrate its usefulness in archaeological research.

Fluctuating early Holocene environmental conditions are cited as influencing the availability and productivity of natural resources in the southern Plateau, which are mirrored in hunter-gatherer adaptive strategies and demographic patterns (Ames 1988). Low populations spread thinly across the landscape used technological and logistical approaches well-suited to a high level of resident mobility. Population densities were controlled by the carrying capacity of the landscape, driven, in turn, by effective temperature and precipitation regimes and their influence on biological populations. During periods of climatic moderation and increased resource productivity, early hunter-gatherers might congregate in higher numbers to exploit rich resources in selected places, leaving a distinct archaeological signature for a limited time. As environmental conditions deteriorated, early populations likely scattered once again, shifting back to adaptive strategies better suited to the use of natural resources with lowered productivity and spatial density.

The *M. falcata* shell $\delta^{18}O$ record shows several distinct periods of climatic fluctuation, which might be used to predict the general nature of early hunter-gatherer adaptive strategies in the southern Plateau under Ames' (1988) model. Early Pacific Northwest populations might be expected to show higher levels of resident mobility during the period between ca. 11,000 and 10,000 yr BP, due to a projected decrease in regional precipitation rates reflecting heightened aridity, which probably resulted in decreased biological productivity in the southern Plateau. Between ca. 9,800 yr BP and ca. 8,000 yr BP, precipitation regimes show some fluctuations between arid and mesic conditions with amplitudes much reduced from the previous period. This might have produced regional environmental conditions that were amenable to increased biological productivity and higher-density hunter-gatherer populations. The latter period of environmental change also corresponds to the transition from Paleoarchaic to Archaic cultural traditions in the region. By ca. 8,000 yr BP, important cultural changes are seen in southern Plateau archaeological sites, represented by new technological and logistical innovations (Ames 1988; Leonhardy and Rice 1970; Sappington 1994).

The latter half of the *M. falcata* shell $\delta^{18}O$ record also corresponds to fundamental changes in southern Plateau prehistory. Cultural complexity, marked by the increased use of camas roots and salmon, and increased settlement along major rivers and tributaries is seen throughout the region after ca. 5,000 to 4,000 yr BP (Ames et al. 1998; Brauner and Stricker 1990; Chance et al. 1989; Leonhardy and Rice 1970; Roll and Hackenberger 1998; Sappington 1994). This period corresponds to increased rainfall and mesic conditions reflected in the *M. falcata* shell $\delta^{18}O$ record. Although the exact link between environmental changes and these cultural developments is not clear, and are dated earlier in some areas (e.g., Brauner 1976), the correlation of hunter-gatherer cultural and environmental change is widespread in the archaeological literature of the region.

Identifying the role of precipitation change associated with these post-5,000 yr BP climate conditions adds yet another degree of resolution to our understanding of the environmental context of late Holocene cultural behaviors in the Plateau. Clearly, however, the correlations discussed here are of a first-order approximation and serve only to highlight potential avenues for further, more detailed, archaeological and geoarchaeological research seeking to elucidate the relationship between prehistoric societies and their environmental contexts. Increasing the database of shell samples will also help to increase the clarity and resolution of this paleoprecipitation record.

Conclusions

Oxygen-18 and carbon-13 values from *M. falcata* shell carbonate samples collected from three archaeological sites located along the Lower Salmon River Canyon of Idaho show several periods of increased and decreased rainfall over the last 12,000 yr BP. Greater aridity is observed during the late Pleistocene and early Holocene, while after ca. 4,000 yr BP precipitation rates increase relative to modern conditions. After ca. 1,800 yr BP, precipitation trends toward modern values. The isotopic record compares closely with numerous regional paleoenvironmental records, reflecting specific conditions of relative humidity. Stable isotope records from freshwater mussels provide a new perspective on late Quaternary paleoclimate conditions and archaeological records in the Pacific Northwest and are a useful addition to investigations of human-environmental interactions in prehistory.

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CHAPTER SIX

LATE QUATERNARY PALEOECOLOGY OF THE LOWER SALMON RIVER CANYON, IDAHO

Introduction

Employing an archaeological approach that seeks, at least in part, to evaluate the changing conditions of the paleoecological context in which prehistoric peoples lived includes many data requirements. In addition to considerations of the social context of prehistoric humans, information on the spatial distribution and relative abundance of natural resources that were exploited by hunter-gatherers plays an important role in building interpretations of why certain cultural behaviors were employed over others at certain points in time (Butzer 1982). By assembling what is known about various natural aspects of a landscape from paleoenvironmental proxy records, it is possible to assess how the combination of different biotic and abiotic components were possibly assembled through time, forming the character of past ecosystems.

Stratigraphic and geomorphic data assembled in field and lab studies were used to address the character and operation of paleoecological components in the Lower Salmon River Canyon (LSRC). A synthesis of paleoenvironmental data reported in the preceding chapters is presented in the sections below, following the format of the LSRC paleoecology model outlined in Chapter 2, and summarized in Figure 93. The various biotic and abiotic components of the paleoecosystem will be discussed through a synthesis of information and predicted conditions that relate to paleoclimatic, paleogeographic, edaphic, vegetative, and faunal components of the LSRC. Conditions in the biotic components of the canyon ecosystem are qualitatively modeled on the basis of the particular habitat requirements of certain key species and how they potentially reacted to changing climate, hydrologic, vegetative, or soil conditions. For the purpose of this study, paleoenvironmental data will be organized into synchronic time-slices in order to present hypothetical reconstructions of canyon paleoecology. The results of these reconstructions will be incorporated into later chapters, forming the basis for discussing prehistoric decision-making in changing environmental contexts.

Paleoclimate

Variations in soil carbonate $\delta^{18}O$ and aeolian fine sand deposition (Davis et al. n.d.) and $\delta^{18}O$ in *Margaritifera falcata* shell carbonate (Davis and Muehlenbachs 2001) provide complementary datasets that are interpreted as proxy paleoclimatic records. During the LP-EH, isotopic records show several abrupt

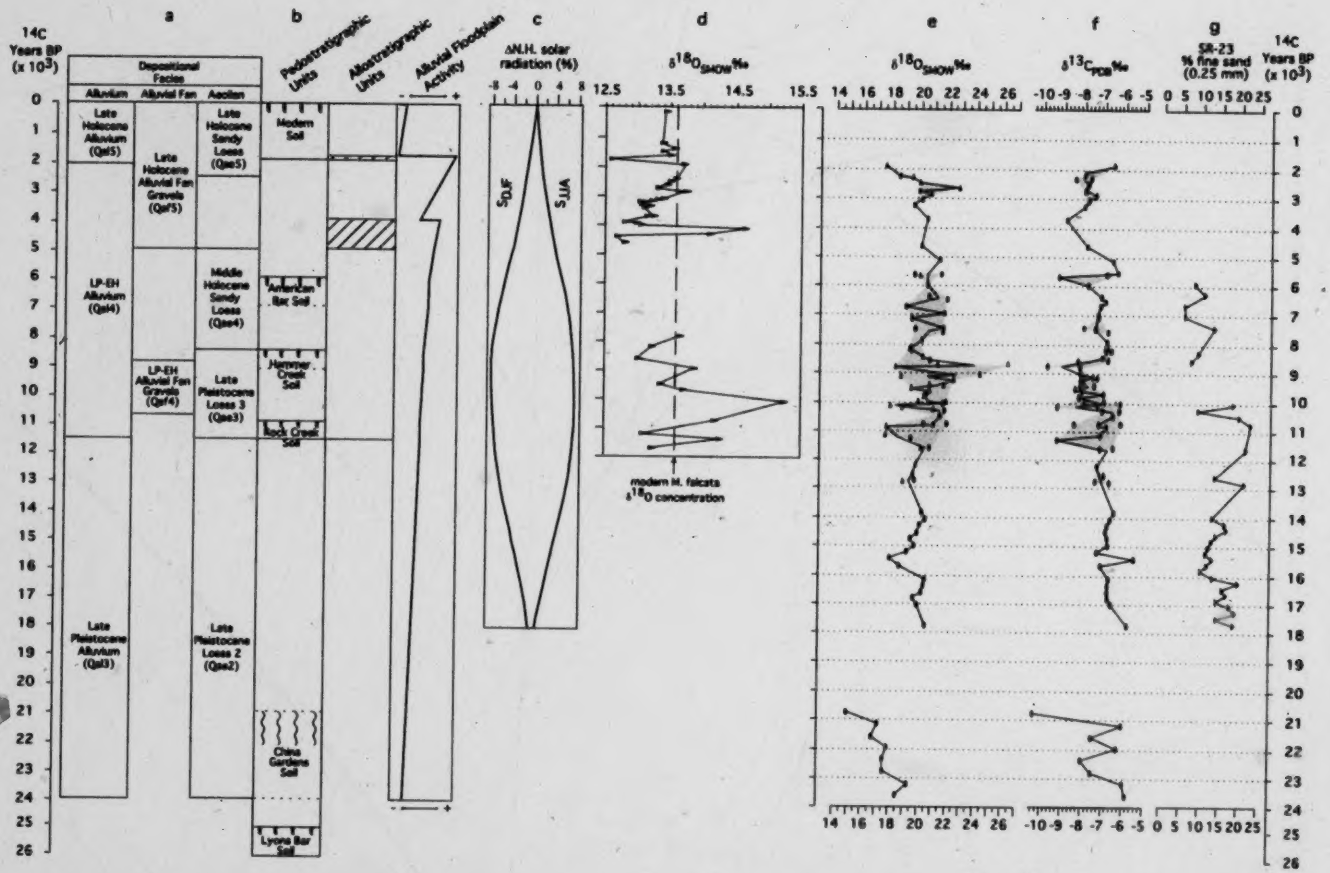

Figure 93. Synthesis of Lower Salmon River Canyon paleoenvironmental and paleoclimate records. Stratigraphic (a) (Davis n.d.), M. falcata shell carbonate $\delta^{18}O$ (b) (Davis and Muehlenbachs, 2001), soil carbonate $\delta^{18}O$ (c) and $\delta^{13}C$ (d) (Davis et al. n.d.), and aeolian fine sand deposition flux (e) (Davis et al. n.d.) datasets are organized relative to uncalibrated ^{14}C years before present (BP).

shifts from high to low compositions, matched by peaks and valleys in the trend of fine sand influx. By the mid-Holocene period, records of isotopic composition and aeolian influx percentages show narrower ranges of variation. After 5,000 yr BP, the δ^{18}O records decline in composition and continue to decrease in amplitude.

These proxy records can be interpreted in climatic terms. Extremes in LP-EH climates, seen in the large variability of isotopic and sand influx rates, are expected, given the effects of orbital geometry on seasonal insolation (Kutzbach 1983). Late Pleistocene to early Holocene summers were apparently very hot and dry while winters were colder and drier than at present. Rainfall regimes match this early climatic variability, with dry conditions projected for the Salmon River basin at ca. 11,400 yr BP, from ca. 10,800 to 9,900 yr BP, and at 9,000 yr BP. Fine sand influx shows a close match with the timing of these isotopic peaks, reflecting rising and falling windspeeds, adding another perspective to the relative aridity of the canyon.

After 8,000 yr BP, rates of aeolian fine sand deposition are lower, suggesting lower windspeeds. Soil carbonate isotopes vary at increasingly lower amplitudes between 8,000 and 5,000 yr BP, meeting predictions of lessened seasonality from insolation inputs (Kutzbach 1983). Because differences in mid Holocene summer and winter insolation rates declined from the preceding period, mean annual mid Holocene temperatures were likely warmer in the LSRC (although average summer temperature and aridity appears higher during the LP-EH).

Paleogeography: Alluvial Behavior

Stratigraphic studies identified two alluvial deposits spanning the last 12,000 yr BP, which date between 12,000 to 2,000 yr BP and 2,000 yr BP to present. (Davis n.d.). Between ca. 12,000 and 9,000 yr BP, alluviation was apparently discontinuous, alternating with periods of increased aridity and aeolian deposition. From about 9,000 to 2,000 yr BP, the Lower Salmon River deposited fine alluvium in the process of extensive floodplain construction. Although two major erosional events are seen at ca. 6,000 to 6,500 yr BP and ca. 5,000 to 4,000 yr BP, alluvial deposition likely resumed immediately. Growth of the low-energy alluvial floodplain occurred throughout the study area by the middle Holocene. The magnitude of this continued alluvial deposition is linked, at least in part, to the effect of middle Pleistocene mass movement canyon fill on the gradient of the Salmon River channel (Davis n.d.). The inability of the Salmon River to remove the diamict fill until the late Holocene resulted in the deposition of low-energy overbank sediments, seen as a large floodplain in nearly all of the study area.

At 2,000 yr BP, the Lower Salmon River incised through its floodplain, removing the remaining slide diamict in the process. With the readjustment of the river channel to a different gradient, the nature of alluvial deposition changed as well. Sedimentation on landforms is different after 2,000 yr BP compared to the rest of the Holocene. Stratigraphic exposures show fining-upwards sequences representing individual flood events separated by erosional unconformities, a pattern most like the modern cycle of seasonal flooding following spring melt of high-altitude snowpack, with only the largest floods depositing alluvium every 100 years or so.

Edaphic Component: Late Pleistocene to Middle Holocene Soils

Two soil units are defined for the LP-MH period (Davis n.d.). The Rock Creek Soil dates between ca. 13,000 and 10,740 yr BP and is commonly seen developed into loess deposits, characterized by weak pedological development, largely limited to slight increases in organic matter, carbonate content, and slight rubification. This soil is interpreted as having formed during periods of surficial stability. Pedogenesis was outpaced by aeolian deposition on several occasions in some sections, pointing to a relatively unstable terminal Pleistocene environmental context. Stable carbon isotope signatures measured in Rock Creek Soil carbonates suggest that a high proportion of C_3 plants grew on its surface during the LP-EH period.

The American Bar Soil developed on aeolian and alluvial substrates in several parts of the study area between ca. 7,000 and 6,000 yr BP. On landforms where rates of deposition were low, American Bar Soil horizons show greater development of argillic, calcic, and structural qualities. Carbon-13 records from American Bar soil carbonates show very low compositions, signalling the presence of a high percentage of C_3 plants.

Vegetation

Variation in soil carbonate $\delta^{13}C$ from various areas in the canyon provides a means of measuring changing proportions in C_3 and C_4 flora through time. Initially, $\delta^{13}C$ records show a great deal of variability, which matches the instability seen in LP-EH $\delta^{18}O$ records. By ca. 10,000 yr BP, plants on the Salmon River floodplain appear as stable, C_3-dominant riparian vegetation populations in contrast to the corresponding climatic variability. This pattern was explained elsewhere as a phreatophytic response to mesic floodplain conditions (Davis et al. n.d.). The percentage of C_3 plants is lower between ca. 8,500 and 6,000 yr BP and remains stable, suggesting little change in riparian vegetation occurred. Changes in seasonality and the expansion of floodplain deposition also occurs between 8,500 to 6,000 yr BP. Between ca. 5,700 and 3,000 yr BP, canyon vegetation oscillates, as evidenced by rising and falling $\delta^{13}C$ compositions.

Little in the paleoclimatic record offers a clear explanation for these mid Holocene vegetation changes. Alluvial stratigraphy shows a period of floodplain erosion between ca. 5,000 and 4,000 yr BP, which probably destabilized the riparian zone, possibly even invoking a draw down of groundwater that provided less moisture for riparian plants. This draw down process might explain the sudden decrease in C_3 plants in tributary floodplains between ca. 5,500 and 5,000 yr BP. Although erosion is seen along the Salmon River between ca. 5,000 and 4,000 yr BP, tributary floodplains accrete once again during this period and C_3 plants repopulate in higher numbers than before. Floodplain deposition and C_3 plant stability is seen again between 3,000 and 2,000 yr BP. As cooler temperatures prevail and precipitation rates rise by 2,000 yr BP, the Salmon River incises deeply through its floodplain, reaching its near-modern position. This fluvial adjustment changed many aspects of the canyon's riparian environment. In most areas, alluviation occurred on much smaller scales after 2,000 yr BP, and with higher energy, producing a narrow floodplain composed of cobble gravels and coarse sediments. Vegetation communities react sharply to these changes in alluvial baselevel, depositional behavior, and availability of soil water. During the last two millennia, drought-tolerant C_4 plants spread along the Salmon River, outcompeting the more mesic C_3 plants, which are restricted to the wetter alluvial fans and tributary canyon bottoms.

The timing of the growth of the alluvial floodplain is linked to the reduction of C_3 plants on canyon slopes. The shrinking biomass and groundcover accompanying this vegetation change would increase slope erosion and sediment inputs to the river (Leopold et al. 1964; Schumm 1969; Knox 1983). Thus, while a decrease in alluvial discharge probably occurred during periods of heightened temperature and aridity, increased sediment load from slope inputs would be expected to trigger aggradation by the Salmon River.

Decomposers and Invertebrates

No information is available on the nature of the late Pleistocene to Holocene decomposer community in the LSRC at this time. Despite this, an indirect assessment of lotic invertebrates can be made by considering the hydrological context through time. Vannote et al. (1980) discuss the importance of carbon reservoirs and rates of downstream movement of organic matter for lotic invertebrates. The productivity of aquatic invertebrates, they argue, has important implications for the productivity and distribution of higher organisms in the river. Under a scenario of lowered channel gradient produced by the introduction of canyon fill following the Devils Garden Slide (Davis n.d.), lotic communities in the study area probably were extremely productive during most of the Holocene, feeding on large amounts of organic matter that accumulated as the Salmon River built its floodplain. This primary productivity likely transfered throughout the food chain, benefiting various fishes, invertebrates, and their predators (e.g., otters, muskrats, raptors). Independent studies aimed at recovering fossil remains of decomposers and invertebrates from late Pleistocene- to middle Holocene-age floodplain sediments in the study area may bear this out. Alternatively, comparisons could be made of the relative abundance of fish and mammal species through time in order to infer the effects of primary productivity at higher levels of the food chain.

The Lower Salmon River currently supports two populations of river mussels: *Margaritifera falcata* and *Gonidea angulata*, with the former occurring in larger numbers in the drainage (Vannote and Minshall 1982). The habitat requirements of the two are slightly different, with *M. falcata* preferring rocky substrates and *G. angulata* tolerant of sandier or silty bottoms (Lyman 1980); however, both species cannot tolerate rapid sedimentation and are easily suffocated. Although attempts are made to use the relative abundance of each species in archaeological assemblages as an indicator of channel conditions (Chatters et al. 1995), mussels are of little use in the study area for this task, since both are commonly found together in any given section of river gravels. Vannote and Minshall (1982) emphasize the importance of stable channel gravels for the longevity of river mussel populations. Mussel populations probably thrived as the presence of the Devils Garden slide diamict promoted alluviation prior to 2,000 yr BP. The question of whether the channel conditions were as laden with fine sediment as its floodplain and, as a result, too inhospitable for either species before 2,000 yr BP is answered by the continued presence of mussels in archaeological sites during the late Pleistocene to Holocene (Butler 1969, Drake 1963; Davis, unpublished data).

Vertebrates

Vertebrate faunal remains are a common occurrence in Plateau archaeological sites, although less so in earlier components. Detailed studies of prehistoric vertebrate populations in the Plateau region include Lothson's (1989) investigation of bighorn sheep hunting, Schroedl's (1973) study of bison, and the work of Schalk (1977) and Butler and Schalk (1986) on anadromous fish populations. Breckenridge et al. (1994) report the discovery of mammoth and extinct bison remains from Tolo Lake, located about seven miles to the west of the study area; however, no dates on these remains were provided and a detailed report is yet forthcoming that may explain the nature of the faunal population encountered. Salmon were likely harvested by 9,800 yr BP at The Dalles Roadcut site along the Lower Columbia River (Cressman et al. 1960), and are also present at Marmes Rockshelter (Gustafson 1972) and Bernard Creek Rockshelter (Casteel 1977) on the Lower Snake River.

Anadromous and Non-Anadromous Fishes

In his comprehensive analysis of anadromous fish resources, Schalk (1977:212) explains that, "riverine environments are the product of the terrestrial environments from which they exact tribute", citing the influence of fluvial discharge and water temperature as primary factors controlling the viability and productivity of salmon populations. Schalk further identifies specific aquatic conditions that negatively influence salmon populations including erosion of spawning gravels and eggs during floods, suffocation of eggs by siltation, overcrowded spawning grounds during low streamflow, extremes in water temperatures, and insufficient discharge during droughts.

Butler and Schalk (1986:243-245) develop several hypotheses regarding the productivity and structure of Holocene anadromous fish resources in the Upper Columbia River basin, drawing on a knowledge of the autecological requirements of salmon and the effects of environmental conditions on their habitats. Between 13,000 and 10,000 yr BP, salmon populations were possibly absent at worst, and unpredictable and of low productivity, at best, in the sediment-laden glacier-fed waters of the Upper Columbia. From 10,000 to 5,000 yr BP, chinook and steelhead runs would occur in several months of the year, and would represent important resources. Because of the extended presence of salmon throughout much of the year, the authors hypothesize that human groups would not require large quantities of salmon for storage, but likely consumed salmon as they were caught. Salmon populations are hypothesized as being reduced during periods of lowered precipitation and fluvial discharge as seen in proxy paleoenvironmental records of this time period. Between 5,000 and 2,000 yr BP, the timing of salmon runs are expected to be restricted to only a few months of the summer season. This situation potentially acted as an impetus for storing large amounts of salmon for consumption during the less-productive winter months. Butler and Schalk (1986) hypothesize that the last 2,500 years were marked by salmon runs that most resembled historic records of fish populations, and provided an important delayed-subsistence resource for Plateau peoples.

Considering the habitat requirements of anadromous fishes, the geologic and paleoenvironmental records from the LSRC suggest that poor conditions for salmon and steelhead spawning and rearing existed until after 2,000 yr BP. Late Pleistocene to early Holocene records show the existence of a low-energy depositional environment in the study area, which corresponded with high summer temperatures and lowered rates of precipitation. This scenario is interpreted to produce low survival rates for salmon in the earliest embryo and fry stages, which likely reduced the numbers of returning adult salmon.

Small Mammals and Birds

Population density and distribution of small mammal populations in riparian zones is largely dependent upon the primary productivity of the aquatic and terrestrial components from which they receive their sustinence and shelter. Where C_3 plants dominate the riparian plant population on an extensive, relatively stable alluvial floodplain, bordered by more xeric slope areas, both terrestrial and aquatic small mammal and bird populations should thrive and occur in relatively high densities.

Small mammalian prey and predator populations in the LSRC possibly included, but were not limited to: beaver (*Castor canadensis*), northern river otter (*Lutra canadensis*), mink (*Mustela vison*), raccoon (*Procyon lotor*), porcupine (*Erethizon dorsatum*), striped skunk (*Mephitis mephitis*), long-tailed weasel (*Mustela frenata*), badger (*Taxidea taxus*), bobcat (*Lynx rufus*), pygmy rabbit (*Brachylagus idahoensis*), mountain cottontail (*Sylvilagus nuttalli*), and coyote (*Canus latrans*) (Csuti et al. 1997). Bird populations generally fall into classes of migratory and resident species, further subdivided into terrestrial and waterfowl specialists. Of these categories, the LSRC might have provided a home for various herons (e.g., *Ardea herodias, Nycticorax nycticorax*), sandhill cranes (*Grus canadensis*), geese (e.g., *Branta canadensis*), the American white pelican (*Pelecanus* erythrorhynchos), long-billed curlews (*Numenius americanus*), ducks (e.g., *Aix sponsa, Anas platyrhynchos, Mergus merganser*), wild turkey (*Meleagris gallopavo*), grouse (e.g., *Bonasa umbellus, Dendragapus obscurus*), mourning dove (*Zenaida macroura*), quail (e.g., *Callipepla californica*), bald eagles (*Haliaeetus leucocephalus*), golden eagles (*Aquila chrysateos*), hawks (e.g., *Accipiter striatus, Buteo jamaicensis*), *owls* (e.g., *Bubo virginianus, Otus kennicotti*), raven (*Corvus corax*), kingfisher (*Ceryle alcyon*), woodpecker (e.g., *Picoides pubescens, P. villosus*), and numerous other smaller species (Csuti et al. 1997), to name but a few possibilites.

Ungulates

Although the habitats that elk, deer, bighorn sheep, bison and antelope inhabit throughout North America vary, certain behavioral and habitat similarities are seen between all species. The composition and structure of the plant communities represents a primary influence on the density and distribution of ungulates. Vegetation provides cover from weather and predators, and critical forage resources. Forage productivity and quality affect the spatial range that individuals must cover to acquire adequate nutrition to successfully compete for mates, reproduce, and survive harsh winter conditions and food shortages. The relationship of forage condition and animal density/distribution is an important theme that is repeated among all ungulates, and is a determinant of the relative availability of large game for hunting.

Elk

Elk habitat requirements are rather varied, reflected in their former New World range, which stretched across the North American continent, into northern Canada, and south along Mexico's major mountain ranges. Despite these geographic differences, elk possess specific habitat requirements that dictate the number of animals that may be supported per unit of land area, and determine the size of an animal's annual home range, or the territory in which annual movements are made. Like other ungulates, elk require three things for their basic survival: access to nutritional food; availability of cover from the elements and predators; and a source of water.

Wildlife studies made on Rocky Mountain elk populations in west-central Idaho and northeastern Oregon provide some general statements about the relationship of animal density to habitat conditions (Leckenby and Isaacson 1982; Leckenby 1984). Elk prefer to live at the forest-meadow ecotone to satisfy both cover and forage needs. A positive relationship is seen between the availability of thermal and hiding cover and the size of an animal's summer home range; thus, greater amounts of cover allows elk to inhabit an area in larger numbers, increasing the density of the animal population. As the extent and quality of thermal and visual cover (C_3 plants) is decreased, the density of elk per hectare will go down. In Leckenby's (1984) study, summer elk range typically included tree stands with 76% canopy closure, with heights averaging 24m (79'). In the winter, elk used 67% of the available thermal cover 90% of the time. Reducing the percentage of vegetative cover, as a result of rising temperature and aridity, would be expected to cause the total available cover to shrink at lower elevations. Under these conditions, elk herds may respond by moving to higher elevations in summer and winter and/or reducing their spatial density at lower elevations, both which would result in fewer elk in the areas adjacent to the LSRC. Conversely, increases in C_3 plants at low elevations would produce positive benefits for elk near the LSRC, corresponding to

Leckenby's (1984:14, Figure 10) observation that, "sizes of home ranges declines about 150 acres with each percentage increase of thermal cover."

Elk are not typically bothered by extreme cold winter tempertaures (Thompson 1988), being better equipped to deal with cold stress than deer and sheep. To cope with low temperatures, elk may feed for longer periods to maintain their caloric requirements for metabolic warming. Critical forage sources are obscured as snow covers grasses. All but the largest of elk, who may continue feeding by pawing patches of ground to remove snow, will soon move to lower elevations when snow depth exceeds 18" (59 cm) (Thompson 1988). As snow continues to accumulate, remaining animals must move to lower elevations as well since energy costs for movement through deep snow (>22" (>72 cm) (Thompson 1988)) increase greatly, requiring even more caloric intake for survival.

Mule Deer

Rocky Mountain mule deer possess basic ungulate requirements of sustinence and shelter across their broad North American range. High densities of mule deer may be found where browse and cover requirements are met. Highly diverse habitats that provide for seasonal needs may produce small home ranges of ≤ 1km^2 (≤ 0.4 mile^2) (Mackie 1994a:283). Forbs, ferns, shrubs, and conifers provide importance sources of protein, in the form of nitrogen, during the summer and fall months that follow highly productive spring growth. Where not buffered by groundwater, most forage loses its nutritional value and digestability by August or September (Parker 1994:313). Mule deer typically avoid large open areas, such as prairies and plains, as they provide little vegetative diversity and places to hide (Mackie 1994b:326). Where topographic relief is varied and vegetation is abundant and diverse, such as river drainages and tributary canyons, densities of mule deer may reach 1.4 to 6.2 animals per km^2 (3.5 to 15.5 per mile^2), as seen in the badlands of eastern Montana and western North Dakota (Mackie 1994b:325).

Because of the marked contrast between mesic canyon bottoms and xeric canyon slopes and rim, mule deer probably remained in the lower elevations of the LSRC for most or all of the year. An example of this behavior is seen in eastern Montana: "Nonmigratory, resident deer live in prairie badlands with streams, riparian areas, and other habitats; the diversity of their habitat meets all of their food and cover needs in winter as well as in summer, so they stay there all year long" (Mackie 1994a:296). Alternatively, mule deer probably spent the spring, summer and fall seasons at the canyon rim-upland plateau ecotone, descending into the shelter of the canyon during winter.

Bighorn Sheep

Although typically found at high elevations in the rough terrains of ridges, escarpments, and mountains, bighorn sheep are also observed in rocky outcrops from the top to bottom of canyons in west-central Idaho. Bighorn eat grasses primarily, but may add shrubs and forbs to their diet during different seasons as they move annually through their home range, which may reach 20 to 40 km^2 (Csuti et al. 1997:443). Less is known of the natural ecology of these animals than elk or deer, due to their extirpation in many areas of the Pacific Northwest in the early part of the 20th century (Berger 1990). Taking cues from the ecology of mule deer and elk, however, it may be safe to assume that the density and distribution of bighorn sheep is dependent on the nutritional quality of forage. Bighorn show fewer needs for cover from predators, choosing to live in steep and rocky "escape" terrains that present difficulties for predators (Wilson and Ruff 1999:348). On this basis, bighorn might be expected to move upslope as grasses on canyon slopes become less nutritious during the summer and fall seasons. During the winter months, bighorn sheep migrate downslope and likely occupied river canyons and valleys prior to the arrival of Euroamerican settlers (Csuti et al. 1997:443).

Bison and Antelope

The grasslands of the Camas Prairie and on Joseph and Doumecq Plains, which border the LSRC, potentially provided prime habitat for bison and antelope during the LP-MH period. The occurrence and distribution of bison is best known from the archaeological record, having disappeared from the Plateau shortly before A.D. 1700 (Schroedl 1973). Remains of *Bison bison* and extinct bison forms are found throughout the southern Plateau in archaeological deposits. Daugherty (1956) reports the discovery of an extinct bison (likely *B. antiquus*) at the Lind Coulee site in eastern Washington. Bison remains were also been excavated along the Lower Snake River at Marmes Rockshelter (Schroedl 1973:1, citing personal communication with Carl E. Gustafson 1971), and at site 45WT7 (Sprague et al. 1968). Butler (1962) recovered bison remains from the early to middle Holocene deposits of Weis Rockshelter, located in a tributary drainage of the LSRC. Also near the LSRC, bison remains were found at Tolo Lake

(Breckenridge et al. 1994), which probably represents a natural death assemblage, as it was not shown to be the result of human hunting.

Pronghorn antelope prefer open shrub steppe and grassland habitats, found in the drier portions of the Plateau (Chatters 1998). Being gregarious animals, antelope will cluster in large herds during the winter months, which could make them susceptible to mass kill strategies (Chatters 1998:38). The success of antelope herds likely depended on the vegetative diversity of upland prairies, as sagebrush and shadscale provides an important source of forage during the winter months (Csuti et al. 1997:442). Because antelope herds typically require summer home ranges of 10 to 20 km^2 (Csuti et al. 1997:442), the geographic size of the prairies near the LSRC probably only supported small populations.

Although the home range needed for *Bison antiquus* herds are not specifically known, comparisons may be made from historical accounts of *B. bison*. Depending on the vegetative and topographic diversity of a region, *B. bison* may make great journeys to acquire suitable forage, having been observed to travel up to 320 km (200 miles) or more from summer and winter ranges on the Plains (Whitaker 1998:852). It is possible that a viable population of *B. antiquus* was supported near the LSRC at the prairie-foothills interface. Today, this habitat is provided where the Camas Prairie lies adjacent to the forested foothills of the Salmon River Mountains and Clearwater Mountains, and where Joseph Plains leads up to the wooded flanks of Craig Mountain.

Ungulate Geophagy and Body Size

Jones and Hanson (1985) report a strong correlation between white-tailed deer weight and soil fertility, noting the importance of calcareous soils in this relationship. Geist (1999) also argued that Pleistocene-age fauna were larger where they fed on plants growing from mineral-rich glaciogenic soils and ingested silts in melting snow (cf. Geist 1990:159). In the case of the Lower Salmon River Canyon, LP-MH soils are much more calcic than late Holocene soils (Davis n.d), as they formed under an environment with higher temperature and evaporation rates. No formal studies are available that address the role of mineral licks (i.e., geophagy) and paleosol productivity on the development of herbivores in the Plateau. The issue of whether the mean body weight of Plateau ungulates was larger during the LP-MH cannot be addressed here, but has important implications for microeconomic studies of early hunting, particularly dealing with issues of caloric yields, risk, and payoffs, and should addressed in the future.

Environmental Scenarios

Although the productivity and distribution of ungulates in a landscape is dependent on many aspects of habitat quality and conditions, the changing effects of cover availability and forage quality on game animals will be addressed by considering how proxy records reflect aspects of paleoclimatic conditions and paleovegetation populations in the LSRC and adjacent uplands. The density and diversity of small mammal and bird habitats will be modeled mainly by assessing the productivity and stability of riparian ecosystems. Success of anadromous fish populations will be considered on the basis of how conditions in the LSRC alluvial system contributed or detracted from spawning and rearing habitats. Four scenarios are presented to address the potential effects of changing climate, geomorphic, and vegetative conditions on faunal populations in and near the study area during the last 12,000 yr BP.

Scenario One (12,000 to 9,000 yr BP): Very Cold, Dry Winters and Very Hot, Dry Summers

Under these conditions, we would expect to see a reduction in timber and shrub coverage in the canyon and in adjacent uplands, with both plant types retreating to riparian zones and less arid slope aspects (north- and east-facing), and an increase in grassland steppe. Lowered precipitation would drive C_3 plants out of poorly-watered canyon bottom areas and onto northern and eastern slope aspects. Overall, forage productivity would be down, resulting in a decreased carrying capacity for ungulates. Elk would be expected to use the canyon less in the spring and early summer, due to a shortened period of vegetative productivity under higher solar insolation rates. In the winter months, elk might be found on the breaks of the canyon and plateau, exploiting the prairie-slope ecotone, and may even be using upland prairies more. Although lowered residual summer productivity in canyon forage would limit elk population residency in the canyon during the winter months, very cold conditions might cause elk to take refuge in canyon bottoms. If temperatures reached extreme and sustained sub-freezing limits, winterkill might be expected to keep ungulate populations down somewhat. Extreme cold temperatures would drive elk to seek out food to maintain metabolic warming, increasing their range during the winter. Overall, the size of ungulate populations might be somewhat lower than today, perhaps limited by climate effects on winter survival rates and winter range productivity. Because of this affect on range productivity, herds and individual animals might be found in lowered densities throughout the immediate area of the canyon and in the adjacent uplands. Mule deer and bighorn sheep might be expected to follow the generally wider movements of elk in seeking forage, but at lower elevations due to the extreme winters. Summer months might find mule deer at the canyon-upland ecotone, or at the timbered edges of the foothills-prairie zone. Winters may be spent on south-facing slopes and in the canyon bottom where harsh weather conditions would be more moderate. Bighorn sheep might use steep and rocky canyon slopes with sunny exposures during the winter months, and may even be found deeper in the canyon. Bison and antelope herds might thrive during this period, if the upland prairies and foothill zones provide a suitable mix of plant types (e.g., bunchgrasses and sagebrush). If vegetation diversity is low, the effects of pronounced seasonality on forage quality might work to suppress the spatial density and overall population size of these grazers, however, as expected with elk. Small mammal and avian populations in the LSRC are expected to be low during this period, due to the lack of a well-developed riparian floodplain with extensive C_3 vegetation. As alluvial conditions provide occasional periods of riparian stability, populations of these smaller animals may thrive for a short time. The large degree of environmental instability that characterizes this period is expected to make these riparian zones rather unpredictable and unreliable from an economic perspective.

Scenario Two (9,000 - 4,500 yr BP): Mild, Dry Winters and Hot, Dry Summers

Lowered forage productivity on slopes and in poorly-watered canyon bottom areas would decrease carrying capacity in the LSRC. Expansion of C_4 plants would increase grassland cover on slopes and in the adjacent uplands, but overall nutritional value of forage would be low, particularly if spring greenup was short, affecting the summer residual nutritive value of plants. Elk may stay at high elevations in winter months if snowpack is low and temperatures are moderate. Mule deer might be expected to move out of the canyons during the summer to find more C_3 plants, remaining within the prairie-canyon ecotone or in the riparian zone during the winter months. During the winter months, bighorn sheep may occupy those reaches of the canyon that offer rocky, rough terrain at nearly any elevation; however, summer heat and dryness would be expected to drive sheep into the uplands. Overall, ungulate populations might be reduced and more dispersed in the study area. As with the earlier period, the absolute and aggregate size of antelope and bison populations should be controlled by the vegetative diversity of the uplands, which would provide much-needed forage resources during harsh winter months. Increased slope erosion following the reduction of vegetative cover on canyon slopes leads to greater sediment input. If precipitation regimes continue to track atmospheric temperatures, as in the previous period, fluvial discharge is expected to be reduced. Coupling the existing sediment load and lowered discharge, alluvial aggradation is expected to occur in the LSRC, and is confirmed in study area stratigraphic records (Davis n.d.). The establishment of a stable and vegetationally-productive riparian zone follows this floodplain aggradation. This riparian ecosystem would provide excellent habitats for small mammal and avian species, which are expected to thrive in this scenario.

Scenario Three (4,500 - 2,000 yr BP): Cool, Wet Winters and Warm, Moist Summers

Winter months may see high elevation forage covered in deep snow. This would make these areas unavailable or stressful for most ungulates, reducing the extent of their winter range. Productivity of forage would increase in the canyon and at the canyon-prairie ecotone as would the coverage of C_3 plants such as coniferous trees and shrubs. These conditions would be favorable to elk and mule deer, but winter snow could be a limitation. Elk winter range would be expected to be located at lower elevations than in the previous period, with populations more abundant on prairies, at the boundaries of the foothills and prairie, and in canyons. Mule deer would be expected to thrive in this context, likely found in larger numbers within the canyons near expanded sources of browse growing in riparian zones and tributary drainages. Nearly all ungulate populations should grow and be found in greater densities in the LSRC under this scenario. Antelope herds may decline if grasses expand at the expense of sagebrush and shadscale, which provide critical winter forage. Bison and antelope populations might expand during this period, as the quality of grazing forage should improve, and also if antelope populations are reduced (lowering competition for forage on the relatively small prairie zones). With the expansion of riparian C_3 vegetation and continued stability of a broad alluvial floodplain in the LSRC, small mammal and avian populations are expected to remain high and perhaps even increase in density.

Scenario Four (2,000 - 100 yr BP): Cool, Moist Winters and Warm, Moist Summers

Apart from a slight reduction in precipitation, this period is climatically similar to the previous period in most regards and is expected to provide similar conditions for ungulate populations. After ca. 2,000 yr BP, vertical and lateral erosion of the Lower Salmon River incised through its floodplain, destroying riparian vegetative communities as the elevation of groundwater tables fell drastically. This period marks the end of low-energy fine-sediment deposition regimes that dominated the geologic record during the previous 10,000 yr BP. The resulting alluvial conditions supported a sparse vegetation population in a newly-organized riparian zone present at the arrival of Euroamerican settlers. Reduction in riparian vegetation and the alluvial floodplain undoubtedly degraded habitat quality for small mammal and avian species, and probably provided less cover and browse for mule deer populations. As a result, the carrying capacity of the LSRC riparian zone was likely lower during this period. These alluvial changes probably produced positive conditions for anadromous fish spawning and rearing habitats, likely promoting a dramatic rise in anadromous fish migration into the Salmon River basin.

The Oasis Effect in the Lower Salmon River Canyon

By looking at the different proxy records from the LSRC during the LP-MH, patterns are revealed suggesting that non-linear biotic responses to climatic and paleogeographic conditions served to organize riparian ecosystems in a way previously unexpected in Plateau canyons. The influence of the Devils Garden Slide canyon fill and early to middle Holocene alluvial sediment inputs from slope erosion had an important effect on the development of canyon riparian ecosystems during the LP-MH. As discussed earlier, the decreased channel gradient produced by the presence of a large, stable channel fill in the study area led to the development of an extensive, well-watered alluvial floodplain.

These conditions probably promoted a degree of riparian biotic productivity not predicted by warming and drying trends seen in regional and canyon proxy records (Davis and Muehlenbachs 2001; Davis et al. n.d.). A direct and relatively linear biotic response to early and middle Holocene warm and dry conditions can be seen in canyon slope vegetation populations, whereas riparian floodplain vegetation responds more directly to erosional events and their effect on groundwater, and less to changes in climate. This asynchroneity between climatic forcing and vegetative response likely created what might be termed an *oasis effect.*

Since the LSRC does not support a large, biotically-diverse and productive floodplain and riparian zone today, how might this particular ecological niche appeared in the past? First, and perhaps most noticable to a prehistoric human observer, the lush riparian vegetative growth in the canyon bottom would contrast sharply with the dry, sparsely-vegetated canyon slopes. The riparian zone most likely supported higher densities of plants and animals than the adjacent slopes and tributary canyons (in most cases), and undoubtedly acted as an important buffer or refugia for deer, fishes, smaller mammals, birds, and mesic plants during perods with heightened aridity and temperatures. Many of the fish and bird species found in these riparian oases would likely be non-migratory, providing a nearly-contstant resource base. Seasonal abundances or aggregations of animals could be exploited in turn, including whitefish, northern pikeminnow, salmonids (although suppressed in the LSRC until after 2,000 yr BP) waterfowl, deer, and mussels (i.e., when lower seasonal fluvial discharge provided the best access). The inner bark, shoots, roots, nuts, berries, seeds, leaves, needles, and fiber of various plants that would thrive along the riparian corridor and on the adjacent canyon slopes would provide a bounty of vegetable resources as well to both faunal and hunter-gatherer populations alike. Riparian oases would be continuous along the river, but limited to where geomorphic and hydrological conditions allowed. For example, floodplain deposition is not expected in the steep- and narrow-walled canyon sections that pass through metamorphic bedrock where the basic foundation for the development of the rich biotic and abiotic components of a riparian zone would be absent.

The Oasis Effect as a Southern Plateau Phenomena

Alluvial behavior among the Lower Snake River stretch now impounded by the Lower Granite dam in southeastern Washington, was very dynamic during the LP-EH. By 10,000 yr BP, Hammatt (1976) identifies an initial stage of floodplain development represented by the deposition of sandy alluvium over river gravels. During high seasonal flow, point bar deposits were eroded and redeposited, resulting in a highly active floodplain. The productivity of the Lower Snake River riparian zone was probably low, as Hammatt (1976:174) hypothesizes that, "although groundwater tables were probably high, the intensity of seasonal erosion limited vegetation to the upslope margins." Despite this, riparian contexts in the Lower Snake River Canyon were likely attractive to early hunter-gatherers, although unstable floodplain conditions possibly restricted the spread of riparian vegetation and its associated biotic inhabitants. The Windust Phase occupation at Marmes rockshelter may reflect this attraction (D. Rice 1972), as evidence of cultural occupation is found in the early alluvium (*sensu* Hammatt 1976) in front of the shelter.

Hammatt identified early Cascade Phase components as occurring during the end of a major aggradation period, marked by the deposition of a unit named the "early alluvium", and characterizes the environmental conditions of this geologic event in the following manner (Hammatt 1976:177):

> There was occasional seasonal overflow and relatively slow moving water which deposited silt. Scouring was minimal over most of the floodplain. Erosive actions of periodic flooding was no longer a limiting factor to the establishment of vegetation. Groundwater tables may have remained high. A lush riparian vegetation probably covered almost the full expanse of the floodplain. The vegetation would have further reduced the erosive effects of periodic floodplain. Relative depositional stability, vegetation cover and the high (but seasonally fluctuating) ***ground water table*** would have promoted soil formation. A moderately developed B horizon formed on large areas of the slowly stabilizing floodplain. (emphasis in original)

And Hammatt (1976:177) also states:

> Around 8,000 years ago the size and the plant biomass of the point bars and may have reached a magnitude which was since not been equaled since (sic.). The carrying capacity for game animals would have been great. It is at this juncture in prehistory that it is easy to hypothesize year round occupation of the canyon, with a heavy composition on hunting. Year round occupation may be indicated archaeologically by the high number of early Cascade sites. Each group probably remained relatively mobile within the canyon as there are no thick accumulations of cultural debris within any one site.

Although not emphasized as such at the time, Hammatt's description of the "early alluvium" and its corresponding environmental aspects suggests that an oasis effect was present in the Lower Snake River Canyon. Combined with evidence from the LSRC, Hammatt's study suggests that the oasis effect might be a widespread phenomena in southern Plateau canyons during the early Holocene. On the basis of similarities between Lower Snake and Lower Salmon River geologic histories, it appears that the lower reaches of southern Plateau river systems probably experienced similar alluvial events during the early Holocene, producing somewhat synchronous patterns of aggradation and degradation. If this is indeed the case, then the role that evolving riparian ecosystems played in the Paleoarchaic-Archaic transition at the scale of the southern Plateau should be considered more closely.

Conclusions

By assembling information on paleoclimate, paleovegetation, stratigraphic, and geomorphic records an effort was made to synthesize what is known about the abiotic and biotic aspects of the LSRC paleoecosystem. These records show a generally rising trend of warming and drying during the period from 12,000 to 4,500 yr BP, followed by a change to wetter and cooler conditions after 4,500 yr BP. Plant populations show different records of response to these climate changes, with slope vegetation responding more directly and linerally to warming and drying than riparian vegetation. The reason for this asynchroneity in canyon vegetation change is linked to the hydrological conditions of the alluvial floodplain, which provided an important water source for riparian plant growth that was absent on canyon slopes. Continuation of these hydrological conditions after 9,000 yr BP resulted in the establishment of a riparian zone dominated by C_3 vegetation, which persisted until ca. 2,000 yr BP. Large-scale alluvial channel incision through the floodplain at ca. 2,000 yr BP reorganized the fluvial hydrology of the Lower Salmon River in the study area, resulting in the rocky, sparsely vegetated riparian corridor seen today.

Predictions of the density and distribution of animal populations in and around the LSRC during the last 12,000 yr BP were made by considering the habitat requirements of different species and character of ecological conditions through time. Conditions favoring seasonal aggregations of mule deer and bighorn sheep were probably always present in the LSRC during the last 12,000 yr BP. Deer and sheep likely used the shelter and forage provided by south-facing canyon slopes and riparian zones more intensively during the very cold winters projected between 12,000 and 4,500 yr BP, and scattered into the uplands during the warmer summers. The density and distribution of elk populations near the LSRC probably remained low until wetter and cooler weather conditions promoted the expansion of the forest-grassland ecotone at lower elevations, perhaps after ca. 4,500 yr BP. Small mammal, bird, and aquatic species likely thrived under the stabilizing and biotically-productive context of a riparian "oasis effect", which is seen in the LSRC from 9,000 to 2,000 yr BP.

Although geoarchaeological and paleoecological studies in other southern Plateau canyons do not specifically identified an asynchronous relationship between upland and lowland plants as contributing to non-analogous situation as projected under the oasis effect, Hammatt's (1976) study of early Holocene alluvial deposition and associated environmental conditions in the Lower Snake River Canyon lends considerable support to this interpretation. This link, tenuous as it may be at this time, represents an important observation on the paleoecology of Plateau river canyons and may hold important clues to be used in interpreting early human-environmental interaction.

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CHAPTER SEVEN

THE COOPER'S FERRY SITE: CULTURAL OCCUPATION ACROSS THE LATE PLEISTOCENE TO EARLY HOLOCENE IN THE LOWER SALMON RIVER CANYON, IDAHO

A version of this chapter by L.G. Davis and C.E. Schweger was submitted for publication in American Antiquity

Introduction

New investigations at the Cooper's Ferry site (10IH73), located in the Lower Salmon River Canyon (LSRC) of west-central Idaho, produced evidence for cultural occupation across the late Pleistocene-early Holocene (LP-EH) transition. A detailed stratigraphic and archaeological record shows multiple periods of site use by hunter-gatherers, spanning the period from 11,410 to after 8,430 BP. Paleoenvironmental records collected from the site provide a basis for understanding the natural context of human occupation during a time of pronounced ecological change. This paper presents the results of test excavations conducted by the University of Alberta in 1997 and will compare the observed stratigraphic and archaeological record with information gathered by Butler (1969) and D.G. Rice (Murphy et al. 1976) during previous investigations at Cooper's Ferry. A synthesis of the available information forms the basis for a new model of early LSRC prehistory. The implications of recently-acquired radiocarbon dates on a long record of cultural occupation are discussed in reference to regional models of prehistory.

The results of this most recent work produced evidence that helps to clarify the early cultural sequence of the southern Columbia River Plateau region. This evidence is of wider interest, as it shows a complete sequence of stemmed and lanceolate point styles beginning at 11,410 BP. The dating of this sequence suggests that early stemmed traditions in the Far West did not necessarily develop from fluted point technologies, but perhaps maintained a continuous technoevolutionary trajectory from an original stemmed point form. Arguments for the existence of Clovis-age lithic co-traditions are supported by the evidence from the Cooper's Ferry site, providing an example of early cultural diversity in Pleistocene-age North America.

To address these issues, this paper will present new information on the geoarchaeological context of early site use, the stratigraphic framework for archaeological assemblages, and a proposed evolutionary chronology of early projectile point technology, as seen at the Cooper's Ferry site. As well, the discovery of an early equipment cache, and the paleoenvironmental context of LP-EH culture change in the LSRC, will also be discussed.

Environmental Setting

The Cooper's Ferry site is located on a small terrace, about 10 m above the confluence of Rock Creek and the Salmon River, 39 miles upstream from the Snake River (Figure 94). The LSRC is located on the eastern edge of the Southern Columbia River Plateau physiographic province. In the area of the Cooper's Ferry site, the Lower Salmon River is deeply entrenched into thick units of the Columbia River Basalt Formation (Maley 1987). The erosive action of the river in this bedrock produced a large, relatively broad canyon with gradual rising slopes. The plateaus of the Camas Prairie and the Joseph and Doumecq Plains border the deeply incised canyon to the north and west, acting as divides between the Clearwater and Snake River Canyons.

The site lies near the boundary of the semi-arid bunchgrass steppe and woodland transition forest vegetation regions of the Plateau (Chatters 1998). Small stands of Ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*) are found at the higher reaches of the canyon, on north- and west-facing slopes, and in consistently active stream drainages. Historically, a cover of grasses, including bluebunch wheatgrass (*Agropyron spicatum*), annual bromes (*Bromes sp. tectorum, B. japonicus, B. brizaeformis, B. commutatus, B. rigidus*), and others including arrowleaf balsamroot (*Balsamorhiza sagittata*) and yarrow (*Achillea millefolium*) were found on lower canyon slopes and in the drier portions of the riparian zone. Streamflow within east and north-facing tributary drainages and lower alluvial fans typically support thickets of various shrub species including hackberry (*Celtus douglasii)*, smooth sumac (*Rhus glabra*), ninebark (*Physocarpus malvaceous*), mountain mahogany (*Cercocarpus ledifolius*), and hawthorn (*Crataegus douglasii*).

Local wildlife are typical of the Pacific Northwest intermontane region. Mammalian species such as bison (*Bison bison*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), mountain sheep (*Ovis canadensis*), moutain goat (*Oreamnos americanus*), coyote (*Canis latrans*), grizzly bear (*Ursus horribilis*), black bear (*U. americanus*), cougar (*Felis concolor*), gray wolf (*Canis lupus*), river otter (*Lutra canadensis*), beaver (*Castor canadensis*), and raccoon (*Procyon lotor*) are identified in the archaeological record of the region. Several fish species reside in the Salmon River. Local, non-migratory

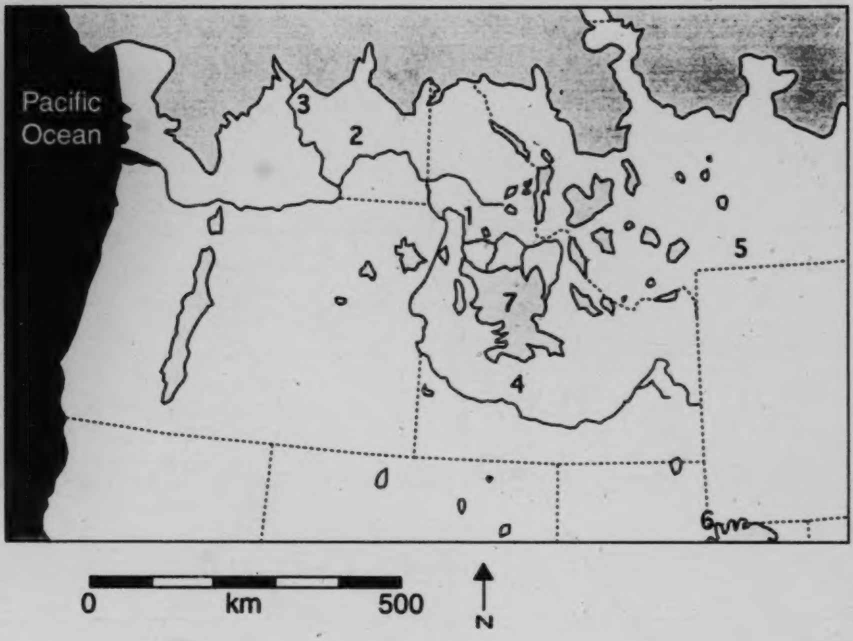

Figure 94. Map showing the location of the Cooper's Ferry site (1) in the Lower Salmon River Canyon, Idaho, and other sites mentioned in text: (2) Lind Coulee site; (3) Richey-Roberts Clovis Cache; (4) Simon Clovis Cache; (5) Anzick Clovis Cache; (6) Fenn Clovis Cache. Distribution of late Wisconsinan Cordilleran and mountain glacial ice (7) follows Flint (1971:Figure 18-4 and Table 18-B).

fish include white sturgeon (*Acipenser transmontanus*), mountain whitefish (*Prosopium williamsoni*), chiselmouth (*Acrocheilus alutaceus*), northern pikeminnow (*Ptychocheilus oregonensis*) and cutthroat trout (*Oncorhynchus clarki*). Anadromous fishes that return to the river include chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*O. mykiss*). Shells of the freshwater river mussel *Margaritifera falcata* are a common occurrence in local archaeological sites (Butler 1969; Drake 1963) and are abundant in the Lower Salmon River today (Vannote and Minshall 1982), whereas the *Gonidea angulata* mussel population is smaller.

Previous Investigations at Cooper's Ferry

B. Robert Butler conducted the first controlled excavations at the Cooper's Ferry site in the summers of 1961 and 1962 and later in 1964. The recovery of a sequence of stemmed points in a stratified sequence from four adjacent 2 m by 2 m excavation units, which form Butler's Trench A, were presented in a report of investigations (Butler 1969). Although this evidence is commonly cited as an example of early Plateau cultural manifestation (e.g., Bryan 1980; Carlson 1983; Ames 1988), chronometric control could not be established for the deeply buried cultural components that yielded stemmed points.

In his doctoral dissertation, D.G. Rice (1972) hypothesized that a technoevolutionary relationship might exist between the Lind Coulee technological tradition (Daugherty 1956) and the Windust cultural type (Leonhardy and Rice 1970). The pursuit of this hypothesis was possibly the impetus for his decision to conduct limited excavations at the Cooper's Ferry site in 1976. Although the results of this investigation were never published, some fieldnotes and a collection of artifacts are available in the University of Idaho archaeological repository. These materials were reviewed by the author in the winter of 1997. Information gleaned from these collections is discussed here in order to present a broader perspective on site geology and archaeological content.

The first stratigraphic profiles to be described at Cooper's Ferry were presented by Butler (1962, 1969). Additional stratigraphic information was recorded by Murphy et al. (1976), as part of D.G. Rice's investigations, in test units close to those placed in 1961 and 1962. Butler (1969) and Murphy et al. (1976) describe a series of sandy deposits with varying proportions of silt and some inclusive rocks, all of which were underlain by well rounded carbonate-coated cobble gravels with an irregular upper boundary. Butler provides interpretations on the genetic origin of the sediments, classifying the fine sediments as aeolian in nature with the inclusion of occasional colluvial clasts from the nearby canyon slope. Varying proportions of calcium carbonate are seen in the sediments, with the highest percentages seen in the lower deposits. The underlying rounded gravels are classified as alluvial, which were eroded (producing the irregular upper boundary) during a deglacial adjustment of the Salmon River, estimated as occurring at ca. 12,000 BP (Butler 1969:38). Murphy et al. (1976) offer no insights on the geomorphic mechanisms reponsible for site formation, nor are age estimates given.

Recent Investigations at Cooper's Ferry

In 1996, a cooperative archaeological research project was developed between the University of Alberta and the Bureau of Land Management (BLM) to evaluate several aspects of LSRC prehistory and Quaternary geology. Within the scope of this research, a single 2 m by 2 m test unit (named Unit A) (Figure 95) was placed at the Cooper's Ferry site in the summer of 1997 in order to attain several research goals, including: (1) confirm the stratigraphy recorded during earlier investigations and to place it in a larger framework of LSRC Late Quaternary geology; (2) collect samples for radiometric dating and; (3) gather a wider array of data for more comprehensive archaeological and geoarchaeological analyses of early human life in the canyon.

Prior to excavating at the Cooper's Ferry site during the 1997 season, several aspects had to be considered since the surface of the bench containing the site experienced much disturbance over the last century. According to local accounts, parts of the Cooper's Ferry site were used as a wagon road and a ferry launch by early euroamerican settlers of the canyon and adjacent Joseph and Doumecq Plains. Later, the Salmon River road was widened, approximating its modern form. Canyon residents recalled various occasions where excess fill material had been placed on the surface of the site. Butler (1969:36) noted disturbed sediments in the upper portions of some areas of the bench, which caused him to abandon excavation in certain test units and to remove turbated fill with a backhoe in others. In 1976, D.G. Rice placed a 3 m by 2 m test unit (designated CF-1) to the east of Butler's Trench A. In 1983, the Bureau of

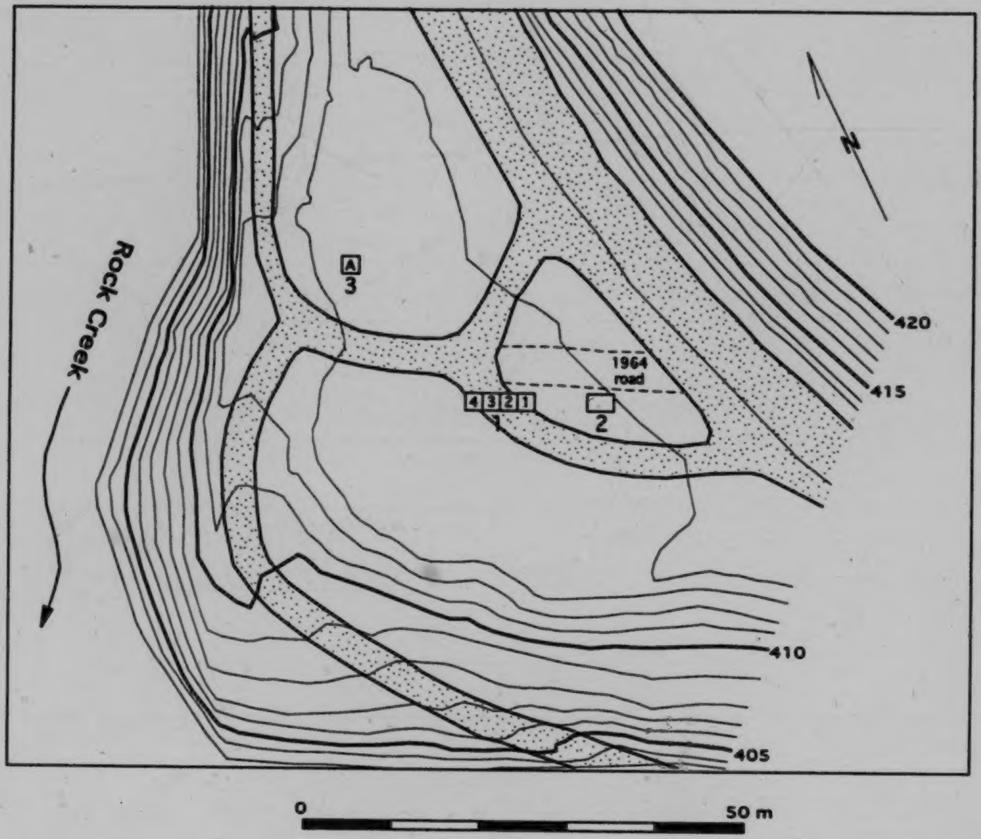
Rock Creek
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Figure 95. Topographic map of the Cooper's Ferry site showing position of excavation units placed by Butler (1969) (1) and Rice (n.d.) (2) in relation to unit A (3). Topographic contours shown in meters above sea level at 1.0 m intervals.

Land Management placed a large quantity of rock fill on exposed cutbanks at the southern edge of the site (see Butler (1969:46) for position of cutbanks), in order to reduce erosion and to protect the site from vandalism (David Sisson, written communication 2001). Based on these considerations, we placed Unit A in the northwestern portion of the bench, in the area of an older road shown in Butler's site map (1969:46), in hopes of avoiding any site disturbance. While the excavation of a test unit in the area of a old road may seem counterproductive to our goals, it was reasoned that while some shallow disturbance might exist in the area, road surfaces are typically excluded from certain site disturbing activites, such as sand quarrying and the digging of garbage pits. Our reasoning was rewarded by the discovery of a long, almost entirely undisturbed stratigraphic record.

Methods

Archaeological excavations followed arbitrary levels, with efforts made to recover items larger in area than 1cm^2 *in situ*. Excavated sediment was passed through 1/8" wire mesh screen cloth, with random samples processed through a finer mesh window screen. Notes, photographs, and drawings were made upon completion of each excavation level. Artifacts and faunal materials recovered during excavations were cleaned, measured, and recorded in a catalog database. The stratigraphic sequence exposed during the 1997 excavation of Unit A was recorded and described in accordance with USDA Soil Survey nomenclature (Soil Survey Survey Division Staff 1993; Birkeland 1984). Sediment samples were taken in 10 cm intervals in a vertical column along a representative section of the north wall (Figure 96). Lithostratigraphic units were defined on the basis of grain size distribution, inclusive mineralogy, and geometry. Grain size distribution of samples was established by dry seiving 100 grams of oven-dried sediment through a graduated set of standardized screen sizes ranging from coarse sand to very fine sand, with the silt and clay fractions collected in a bottom pan (following Wentworth 1922). Textural descriptions were made in accordance with USDA Soil Conservation Service guidelines (Soil Survey Division Staff 1993:138).

In order to determine geomorphic processes responsible for the formation of lithostratigraphic units in the LSRC, an extensive study of late Quaternary sediment granulometry was conducted (Davis n.d.). In this study, nearly 400 sediment samples were processed and dry sieved to separate out grain sizes between -2

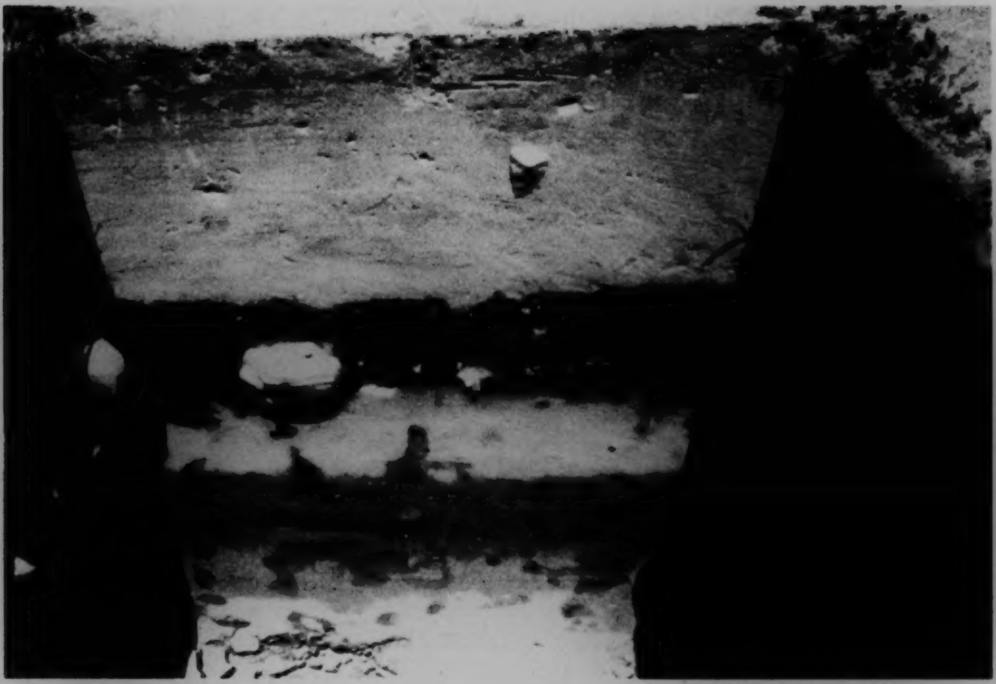

Figure 96. Oblique photo of Unit A north wall stratigraphic profile.

phi to 5 phi. The cumulative frequency of a representative sample of this granulometry database was calculated and plotted. The resulting graphic distributions of grain size data were used in conjunction with other stratigraphic data to establish parameters for the granulometry of colluvium, alluvium, and aeolian sediments in the LSRC.

Stable oxygen-18 and carbon-13 values were established for samples collected in a stratigraphic sequence in order to provide a perspective on paleoclimate and paleoecology. Isotopic studies of LSRC soil carbonates (Davis et al. n.d.) and mussel shell carbonates are reported elsewhere (Davis and Muehlenbachs 2001), and are only summarized here. Oxygen-18 and carbon-13 signatures of soil carbonates are interpreted as reflecting changes in temperature, aridity and the relative percentage of C_3 plants at the site level. The oxygen-18 signature of *M. falcata* mussel shell carbonates records variability in the isotopic signature of river water, which is interpreted as a proxy indicator of precipitation regimes that affect the Salmon River basin (Davis and Muehlenbachs 2001). Percentages of organic matter and calcium carbonate in site sediments were established by a loss on ignition method, in which 10 g samples of dry sediment were heated to 550° C and 1000° C; differences in weight after each temperature stage were interpreted as reflecting proportional losses in organic matter and carbonate, respectively.

Stratigraphic Record

A synthesis of the lithostratigraphy, pedostratigraphy, stable isotope geochemistry, cultural stratigraphy, and chronostratigraphy for Unit A are presented in Figure 97, and will be discussed in the sections that follow. Correlations will be made between the geologic record reported in Unit A and in Butler's Trench A in order that a larger, more comprehensive geologic and archaeological framework for the Cooper's Ferry site is established. Within this framework, the nature of site formation processes and the cultural occupations themselves will be better appreciated.

Unit A Lithostratigraphy

Nine lithostratigraphic units (Table 11) and three pedostratigraphic units were identified in Unit A. The designation of these units and an illustration of the stratigraphic profile of the north wall of Unit A is

Unit 1 (LU 1). Rounded to subrounded basalt clasts of fine pebble to medium cobble size with no apparent bedding structure in a relatively poorly sorted, clast-supported matrix. Carbonates coat and cement clasts together in some areas.

Unit 2 (LU 2). A yellowish brown (10YR5/4), massive, moderately well sorted sand. Calcium carbonate is dispersed throughout the sediment matrix. This lowermost sand has a sharp irregular basal boundary that appears to be conformable.

Unit 3 (LU 3) (S1). A brown (10YR5/3), massive, fine sandy loam bounded below by a gradual smooth conformable boundary. Calcium carbonate is present as fine filaments throughout the deposit.

Unit 4 (LU 4). A yellowish brown (10YR5/4), massive, fine loamy sand with a clear wavy conformable lower boundary. Calcium carbonate is seen as fine filaments and diffuse compositions.

Unit 5 (LU 5). A horizontal deposit of brown (10YR5/4), massive, moderately well-sorted sand without visible structures. Mica flakes and biotite accompany a large percentage of quartzitic and plagioclase sands. The lower boundary of this unit is sharp, conformable, and retains several irregular lobate structures suggesting soft sediment deformation, similar to those seen in the immediately overlying unit.

Unit 6 (LU 6) (S2). Brown (10YR4/3), massive, loamy sand. The percentage of grain sizes greater than coarse sand increase in this unit. The lower boundary of the unit is conformable with a sharp and irregular form. Lobate extensions of sediment reaching down into the underlying geologic unit are interpreted as evidence of soft sediment deformation during alluviual deposition. Prehistoric site occupation appears to have contributed to some sediment disturbance here as well.

Unit 7 (LU 7). A thin deposit of dark grayish brown (10YR4/2), massive, fine loamy sand, which retains a sharp wavy lower boundary that dips slightly to the west.

Unit 8 (LU 8a and LU 8b). A grayish brown (10YR5/2), massive, medium sand, with poorly-preserved evidence of horizontal bedding in few places. The unit is dominated by quartz and plagioclase sands and includes biotite, mica flakes, and a small percentage of silt. A sharp bedding line is seen in all walls of Unit A, dipping downward to the northwest corner. This sharp, wavy bedding line is composed of a fine silt with some carbonate accumulation, and is thought to represent an erosional unconformity and a brief change in depositional energy. Although LU 8 is divided into two units on the basis of thie erosional unconformity, LU 8a and LU 8b appear identical in nature. LU8a shares a sharp wavy boundary with LU 7.

Fill (S3). Composed of a dark brown (7.5YR3/2), massive, medium to fine loamy sand with occasional gravels. Thin, horizontal layers of compacted sediment were observed in some areas of the unit, corresponding to old road surfaces. Historic and modern debris was recovered from these sediments. The lower boundary of the unit is clear and irregular, and is unconformable due to cultural disturbance. This deposit relates to local accounts of fill disposal during historic road building activities.

Table 11. Description of lithostratigraphic units (LU) and pedostratigraphic units (corresponding pedostratigraphic unit put into parentheses (e.g., S2)) encountered at 10IH73, Unit A.

provided in Figure 97. Results of granulometric analyses are presented in Table 12.

Unit A Pedostratigraphy

Pedogenic development is seen in three geologic deposits at Cooper's Ferry and are designated S1, S2 and S3 (corresponding to their A horizons) (Figure 97, Tables 11 and 13). The first (S1) is seen developed in LU 3 and penetrates into the upper portion of LU 2. This zone of pedologic development is marked by slight increases in carbonate content and organic matter, which decrease with depth. This soil horizon is clearly incipient in nature due to its low level of pedogenic development. This weak pedogenic development apparently kept pace with sedimentation for some time; however, sedimentation rates seem to increase during the deposition of LU 4, outpacing soil development.

The second pedogenic horizon (S2) is present in LU 6, identified by an increase in organic matter and carbonate content. This paleosol is likely cumulic in nature due to an absence of well-developed structure, clay skins, or other clearly-defined pedogenic horizonation; carbonate filaments are commonly seen in this unit.

The third pedogenic horizon (S3) corresponds to the Fill, where percentages of organic matter are highest and a weak granular structure developed. This incipient soil horizon is somewhat disturbed by the effects of historic activities at the site and is given an Ap designation.

Unit A Allostratigraphy

The nature of contacts between lithostratigraphic units are defined as either conformable or unconformable on the basis of whether they represent periods of continued deposition, surficial stability, or erosion (Waters 1992:68-73). Disconformable stratigraphic boundaries show a break in time in a stratigraphic sequence (e.g., soil development or erosional unconformities) and provide boundaries for allostratigraphic units (NACOSN 1983). The linearity of time in Unit A stratigraphy can be seen in the stratigraphic boundaries between the nine lithostratigraphic units described above (see Figure 4).

Unconformable boundaries are seen between four deposits in Unit A stratigraphy. The first of which is seen between the base of the Fill and the top of LU 8b. This unconformity was created as fill

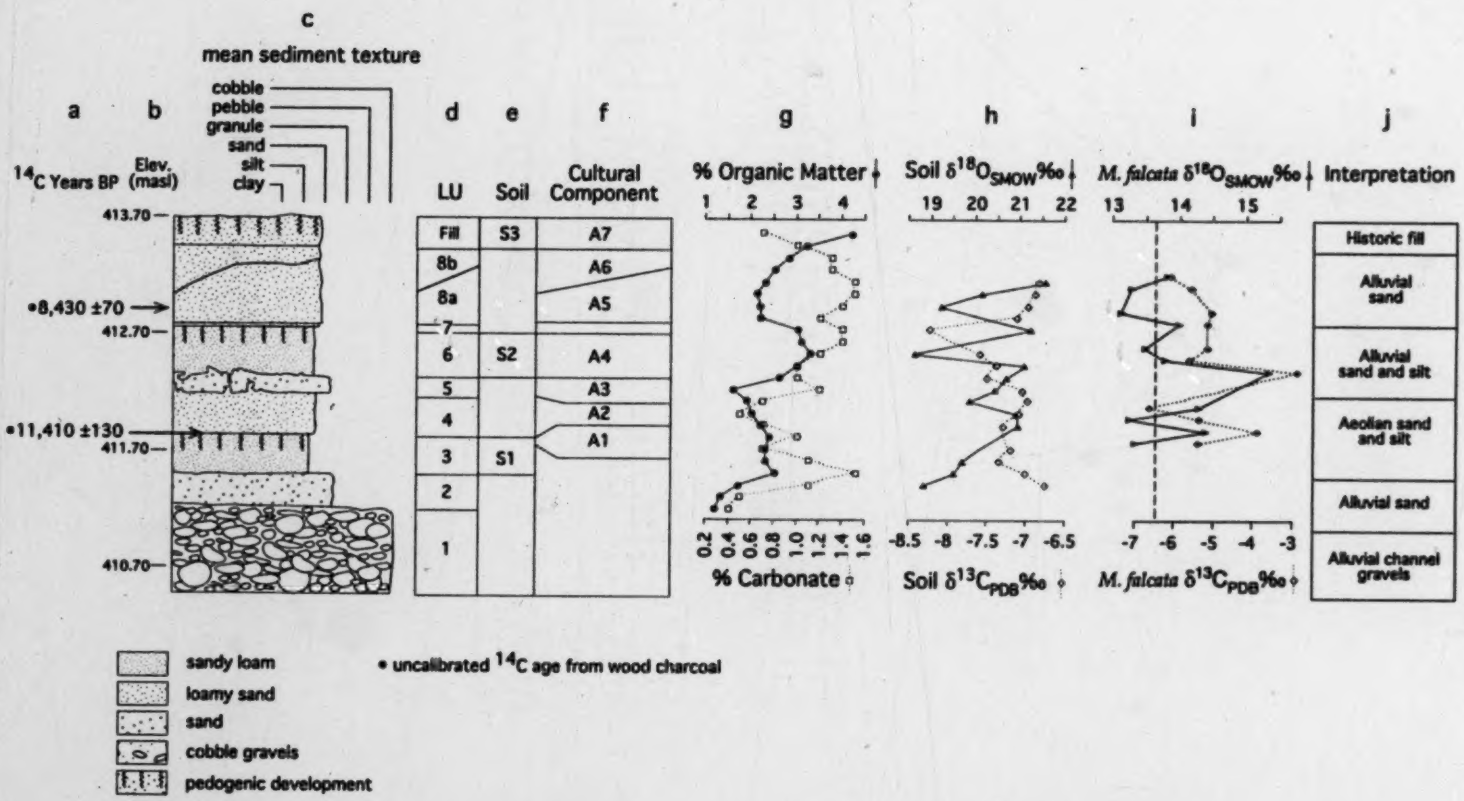

Figure 97. Synthesis of stratigraphic data from Unit A, Cooper's Ferry site: uncorrected radiocarbon dates (a); depth shown in meters above sea level (b); mean sediment texture follows USDA standard (Soil Survey Staff 1993) (c); lithostratigraphic units (LU) (d); pedostratigraphic units (e); cultural components recovered from site (f); percentage of soil organic matter and calcium carbonate (g); stable isotope geochemistry of soil carbonates (h); oxygen-18 values from *M. falcata* shell carbonate (i); and interpretation of depositional environment (j).

Elevation (masl)	≥coar. sand	med. sand	fine sand	v. fine sand	silt+clay	%OM	%CaCO3	LU
413.60	7.0	17.3	32.7	23.5	19.0	4.2	0.7	Fill
413.50	6.8	11.8	22.1	37.8	21.5	3.2	1.0	
413.40	4.6	13.3	35.4	28.9	16.9	2.8	1.3	8b/8a
413.30	5.4	14.8	35.5	27.5	15.9	2.5	1.3	
413.20	2.8	15.0	36.9	29.4	15.5	2.3	1.5	
413.10	2.8	13.5	31.1	38.5	13.0	2.1	1.5	
413.00	3.5	13.2	37.8	30.0	15.2	2.2	1.4	
412.90	2.7	12.4	37.1	30.7	16.7	2.2	1.2	
412.80	4.7	14.2	31.5	25.9	23.1	3.0	1.4	7
412.70	4.1	16.8	30.2	23.0	25.0	3.1	1.4	6
412.60	5.0	18.2	34.8	23.4	17.7	3.3	1.2	
412.50	4.3	18.3	34.2	24.6	17.6	3.0	1.0	
412.40	5.2	16.4	33.5	26.5	17.4	2.6	1.0	
412.30	5.2	19.7	28.6	31.8	14.6	1.6	1.2	5
412.20	4.0	22.9	41.1	22.1	9.0	1.9	0.7	
412.10	2.0	13.5	34.7	30.6	18.6	2.0	0.5	4
412.00	1.5	10.7	32.8	35.2	19.1	2.2	0.7	
411.90	0.5	5.3	24.9	38.0	30.7	2.4	1.0	
411.80	0.4	7.3	33.4	32.2	25.2	2.3	0.7	3
411.70	1.0	10.0	28.0	30.5	29.7	2.3	1.1	
411.60	0.3	12.0	25.5	26.7	34.6	2.5	1.5	
411.50	0.6	22.6	44.0	18.8	12.9	1.7	1.1	2
411.40	1.5	21.9	55.3	15.8	5.4	1.3	0.5	
411.30	2.5	21.1	57.3	14.5	4.4	1.2	0.4	

Table 12. Grain size distribution and lithostratigraphic units of Cooper's Ferry, Unit Elevation reported in meters above sea level, LU = lithostratigraphic unit. All grain size classes reported as percentage of 100 g samples.

LU/Ped.	Horizon	Elevation	Lower Boundary	Color	Texture	ST	DC	MC
Fill (S3)	Ap	413.60- 413.50	clear, irregular	7.5YR3/2	loamy sand	granular	loose	loose
8b/8a	C	413.40- 413.00	sharp, wavy	10YR4/3	sand	massive	loose	loose
7	2C	412.90	sharp, wavy	10YR4/2	loamy sand	massive	loose	loose
6 (S2)	Awb1	412.80- 412.50	sharp, irregular	10YR5/4	loamy sand	massive	loose	loose
5	3Cb1	412.40- 412.30	sharp, irregular	10YR5/4	sand	massive	firm	loose
4	4Cb1	412.20- 412.00	clear, wavy	10YR5/3	loamy sand	massive	firm	friable
3 (S1)	2ACkb2	411.90- 411.60	gradual, smooth	10YR5/3	sandy loam	massive	firm	friable
2	5Cb2	411.50- 411.30	sharp, irregular	10YR5/3	sand	massive	firm	friable
1	6Cb2	411.20+						

Table 13. Pedologic descriptions of Unit A stratigraphy. LU/Ped. = lithostratigraphic unit with corresponding pedostratigraphic unit put into parentheses; Horizon = pedological horizon; Elevation = unit elevation (in meters above sea level); Color = dry Munsell color; Texture = soil texture; Structure = soil structure; DC = dry soil consistence; MC = moist soil consistence.

produced during historic road building in the LSRC was dumped on the surface of the site. The boundary between LU 8a and LU 8b is thought to represent a period of erosion followed by a brief shift in depositional energy, which laid down a thin silty deposit. The contacts between LU 7-LU 6 and LU 4-LU 3 mark episodes of renewed deposition following periods of temporary surficial stability, reflected in weak soil development. Burial of these soil surfaces was not preceded by an erosional event, which commonly produces lagged accumulations of clastic materials (including artifacts) or scour features. The remaining boundaries between LU 6-LU5, LU 5-LU 4, LU 3-LU 2, and LU 2-LU 1 all appear to be conformable. These contacts are interpreted as reflecting changes in the geomorphic mode of deposition (e.g., alluvial to aeolian) or fluctuations of energy along a depositional continuum (e.g., higher-energy alluvial gravel emplacement changes to lower-energy sand deposition following alluvial channel adjustment).

Unit A Stable Isotope Geochemistry

In the lowest deposits of the Unit A stratigraphy (Figure 97), between 411.4 and 411.9 masl, soil carbonate oxygen isotopes (Table 14) follow a pattern of rising composition from 18.8‰ to 20.9‰, while carbon isotopes decline in value from -6.8‰ to -7.3‰. Isotope compositions of $\delta^{18}O$ in soil carbonates between 412.0 and 412.9 masl range between 20.9‰ to 19.2‰, and $\delta^{13}C$ between -7.1‰ to -7.0‰. Above 412.9 masl, soil carbonates produced isotopic values between 20.1‰ and 19.9‰ for $\delta^{18}O$, and -6.9‰ and -7.5‰ for $\delta^{13}C$. Throughout the Unit A stratigraphy, $\delta^{18}O$ values span a total of 3.0‰ accompanied by a total shift of 1.5‰ in carbon-13 values.

Unit A Cultural Stratigraphy

Evidence of cultural occupation was found in nearly all lithostratigraphic units of Unit A (Tables 15-17). Only a small percentage of the excavated material is clearly intrusive into some deposits, seen either in rodent burrows or within the fill of prehistoric pits. Distinct occupation surfaces were easily defined where recognizable features and artifact clusters are associated with geologically-defined surfaces; this was observed most clearly near the upper boundary of LU 3 where the top of a pit cache and a scatter of cultural materials were located. In the case of repeated site occupation during periods of steady sedimentation, cultural materials are dispersed through the deposit and clear living surfaces are not as easily defined (Ferring 1986). Examples of this latter case were observed in LU 4 to LU 8. Figure 98 gives a perspective on the intensity of site use, as reflected in a backplot of cultural materials mapped *in situ*.

Seven cultural components were defined at Unit A (Figure 97). These components included Lind Coulee stemmed points (Daugherty 1956) and sparse occupations in the lower portion of the site, which changed to Windust, and later to Cascade points (Leonhardy and Rice 1970). These latter point types are associated with artifact-rich occupation surfaces toward the top of the profile. Four cultural components are thought to date to the late Pleistocene-early Holocene period, with the remaining three younger than 8,400 BP. Discussion in this section will address the early archaeological remains, cultural components compared between those excavated from Unit A and Butler's Trench A, and a synthesis of cultural occupation at Cooper's Ferry.

Component A1. Associated with LU 3 and a paleopedogenic horizon of the Rock Creek Soil (S3) (Davis n.d.), component A1 produced the earliest-dated cultural occupation in Unit A. At the upper limits of LU 3 a circular pit feature was discovered. The surface of the pit began at 411.80 meters above sea level (masl) and extended into the gravels of LU 1 to a depth of 410.49 masl (Figures 99 and 100). Debitage was found on and in a paleosol developed in LU 3; and is thus considered contemporaneous with the excavation of the pit feature, due to the stratigraphic association. The matrix of the pit fill was comprised of mixed sandy and sandy loam sediments and included rounded cobble clasts. The poorly sorted nature of the matrix was created as the pit was refilled, and sharply contrasted with the surrounding sediments, allowing for a clear definition of the pit wall boundaries. Within the pit feature, several lithic artifacts were found, including a large scraper, a large blade-like flake, fragments of two cores, and four stemmed projectile points (Figures 101 and 102). These points (Figure 103) are identical to specimens recovered at the Lind Coulee site in eastern Washington by Daugherty (1956).

Compared to other components, lithic tools and debitage were recovered in relatively modest quantities from the surface of and within LU 3 and from the fill of the cache pit (Tables 15-17). Notably, more formed tools were found from within the cache pit than from LU 3. Cache pit artifacts include the four Lind Coulee stemmed points made from locally available microcrystalline quartz materials, two blades,

Elevation	δ^{18}O‰	δ^{13}C‰
413.60		
413.50	19.9	-7.5
413.40		
413.30	20.1	-7.5
413.20	20.0	-7.3
413.10	21.6	-6.9
413.00	20.1	-6.9
412.90	19.2	-7.0
412.80	20.2	-7.1
412.70	21.2	-8.2
412.60		
412.50	18.6	-7.6
412.40	21.1	-7.4
412.30	20.7	-7.5
412.20	20.4	-7.1
412.10	19.8	-7.0
412.00	20.9	-7.1
411.90	20.9	-7.3
411.80		
411.70	20.0	-7.2
411.60	19.7	-7.4
411.50	19.5	-7.0
411.40	18.8	-6.8
411.30		

Table 14. Stable isotope geochemistry of soil carbonates from the Cooper's Ferry site, Unit A. Elevation in meters above sea level; Oxygen-18 values reported in permil (‰) relative to the SMOW standard and carbon-13 values reported relative to the PDB standard.

LU	Component	Debitage		Chalcedony		Opal		Obsidian		CCS		Basalt		Metamorphic		SR Greenstone	
		N	Wt. (g)	N	Wt. (g)	N	Wt. (g)	N	Wt. (g)	N	Wt. (g)	N	Wt. (g)	N	Wt. (g)	N	Wt. (g)
Fill	A7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
8	A6/A5	11020	2037	4535	746.9	6025	1190.4	10	1.0	0.0	0.0	196	47.2	19	8.8	23	3.4
7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	A4	22095	6502	10287	2404.7	10956	2134.1	70	3.8	71	69.5	335	1404.8	37	132.7	54	4.1
5	A3	4084	1349.6	2641	602.9	1213	548.3	10	0.9	1	2.5	195	172.5	2	5.9	10	1.0
4	A2	4629	1435.8	2989	380.7	1261	498.3	11	1	7	10.2	316	220.7	2	8.7	29	2.9
3	A1	901	196.2	408	53.9	459	115	4	0.4	0	0	22	22.8	3	1.4	2	0.2
Cache	A1	800	1212.9	407	176.9	228	139	0	0	4	1.4	81	31.1	3	2.4	7	0.8
2	?	224	81.8	139	28.1	63	44.2	1	0.1	8	0.6	8	1.8	2	1.1	3	4.0

Table 15. Stratigraphic distribution of debitage (CCS = cryptocrystalline silicate; SR Greenstone = Salmon River Greenstone) by material, quantity, and weight at 10IH73, Unit A.

LU	Component	Bone (g)	M.Shell (g)	S.Shell (g)	Fish Bone (n)	Tooth (n)	Tooth (g)	FCR (n)	FCR (g)	Hearths (n)	Pits (n)
Fill	A7	--	--	--	--	--	--	--	--	--	--
8	A6/A5	235.9	84	87.6	85	45	2.4	0	0	0	0
7	--	--	--	--	--	--	--	--	--	--	--
6	A4	367.2	295.9	19.6	126	87	10.7	32	938.5	0	1
5	A3	27.1	7	8.5	7	0.6	7	57	36.6	0	0
4	A2	29.5	9	10.3	15	6	0.6	1	22	0	0
3	A1	5.3	1.9	2	0	0	0	0	0	0	1
Cache	A1	25.8	0.3	0.5	0	5	0.2	0	0	0	1
2	?	11.6	0.3	0.4	1	2	0.1	0	0	0	0

Table 16. Stratigraphic distribution of faunal material (M.Shell = mussel shell; S.Shell = snail shell), fire cracked rock (FCR), hearth, and pit features at 10IH73, Unit A by weight (g) and quantity (n).

LU	Component	Bifaces	Blades	Cobble Tools	Cores	Groundstone	Hammers	Modified Flakes	Points	Unifaces
Fill	A7	--	--	--	--	--	--	--	--	--
8	A6/A5	32	11	0	1	0	0	20	6	2
7	--	--	--	--	--	--	--	--	--	--
6	A4	39	6	2	9	2	3	61	5	12
5	A3	7	2	0	1	0	0	9	2	0
4	A2	4	0	1	4	0	1	10	3	3
3	A1	2	0	0	0	0	0	0	0	0
Cache	A1	4	2	0	2	0	1	0	4	1
2	?	0	0	0	0	0	0	0	0	0

Table 17. Quantities of lithic tools at 10IH73, Unit A by lithostratigraphic unit (LU) and cultural component.

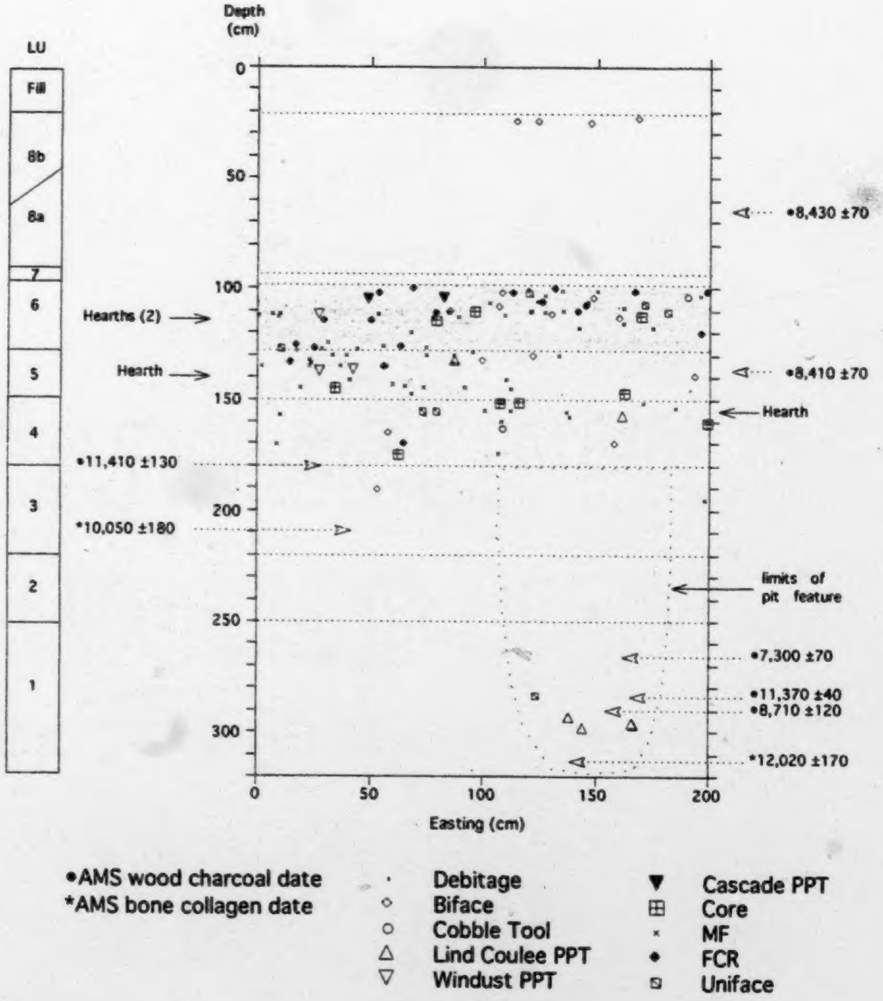

Figure 98. Backplot of cultural materials plotted in situ in Unit A, compared to stratigraphy.

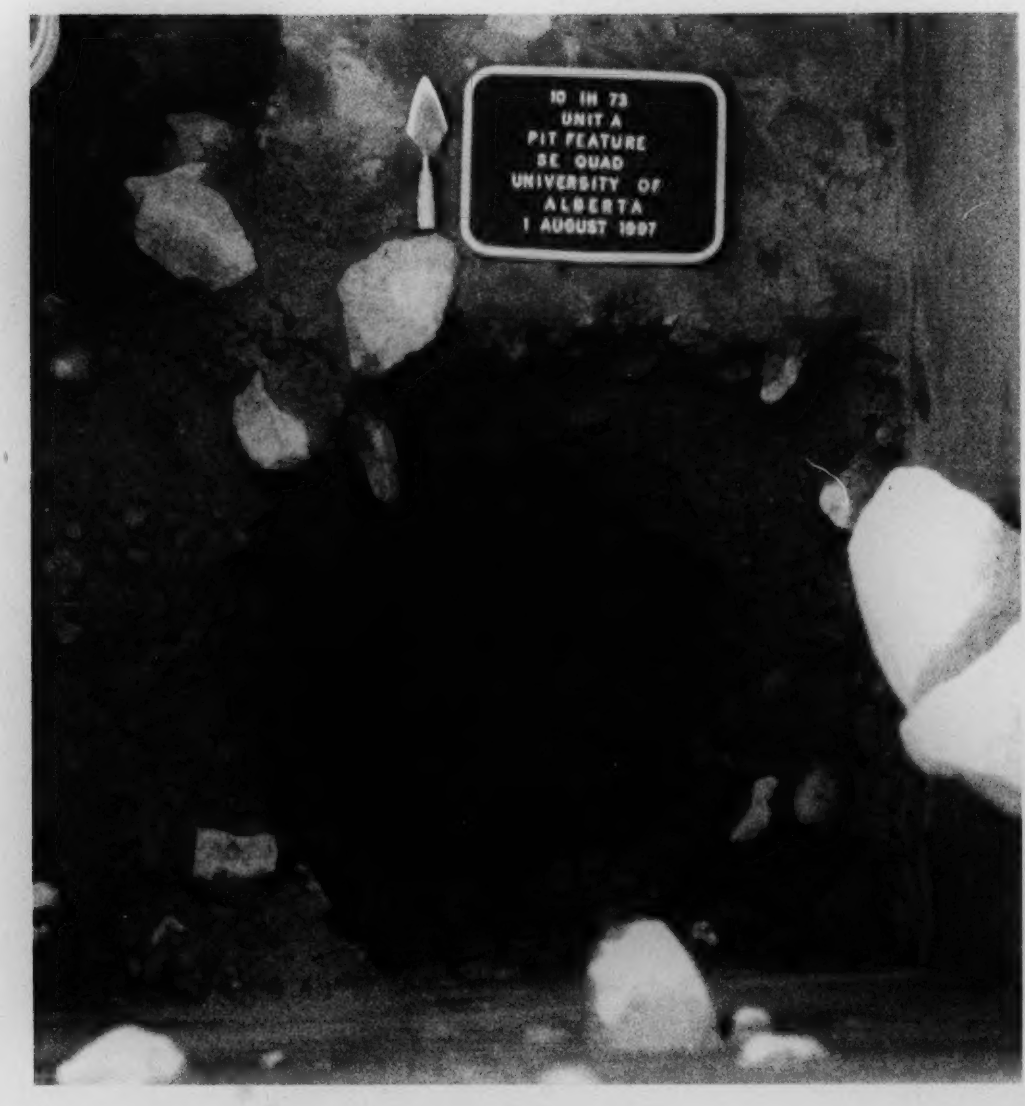
10 IH 73
UNIT A
PIT FEATURE
SE QUAD
UNIVERSITY OF
ALBERTA
1 AUGUST 1997

Figure 99. Plan photo of pit feature, unit A, southeastern quadrant.

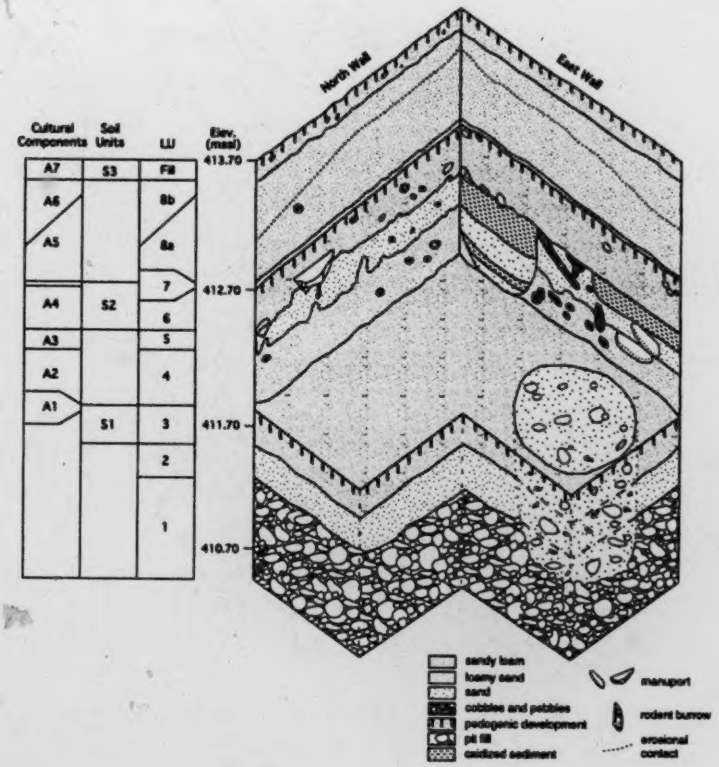
North Wall
East Wall
Cultural Components
Soil Units
LU
Elev. (masl)
A7
A6
A5
A4
A3
A2
A1
S3
S2
S1
Fill
8b
8a
7
6
5
4
3
2
1
413.70
412.70
411.70
410.70
sandy loam
loamy sand
sand
cobbles and pebbles
pedogenic development
pit fill
oxidized sediment
manuport
rodent burrow
erosional contact

Figure 100. Three-dimensional projection of Unit A, showing relationship of lower pit feature with site stratigraphy.

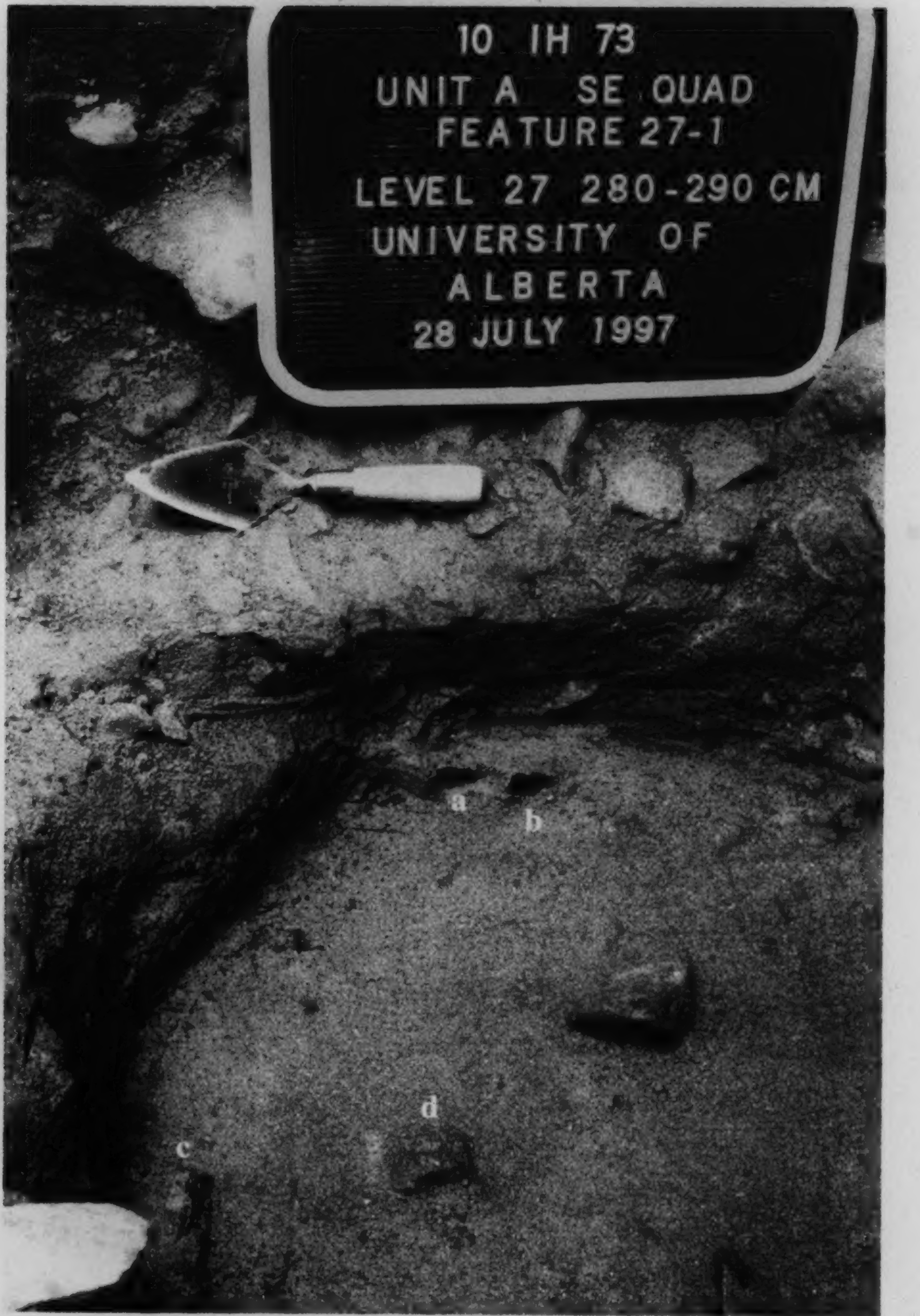
10 IH 73
UNIT A SE QUAD
FEATURE 27-1
LEVEL 27 280-290 CM
UNIVERSITY OF
ALBERTA
28 JULY 1997
a
b
c
d

Figure 101. Photo of stemmed points (a, b, c) and artiodactyl bone (d) in situ, Unit A, level 27, southeastern quadrant. A fourth stemmed point was found near the bone fragment, at the top of level 28.

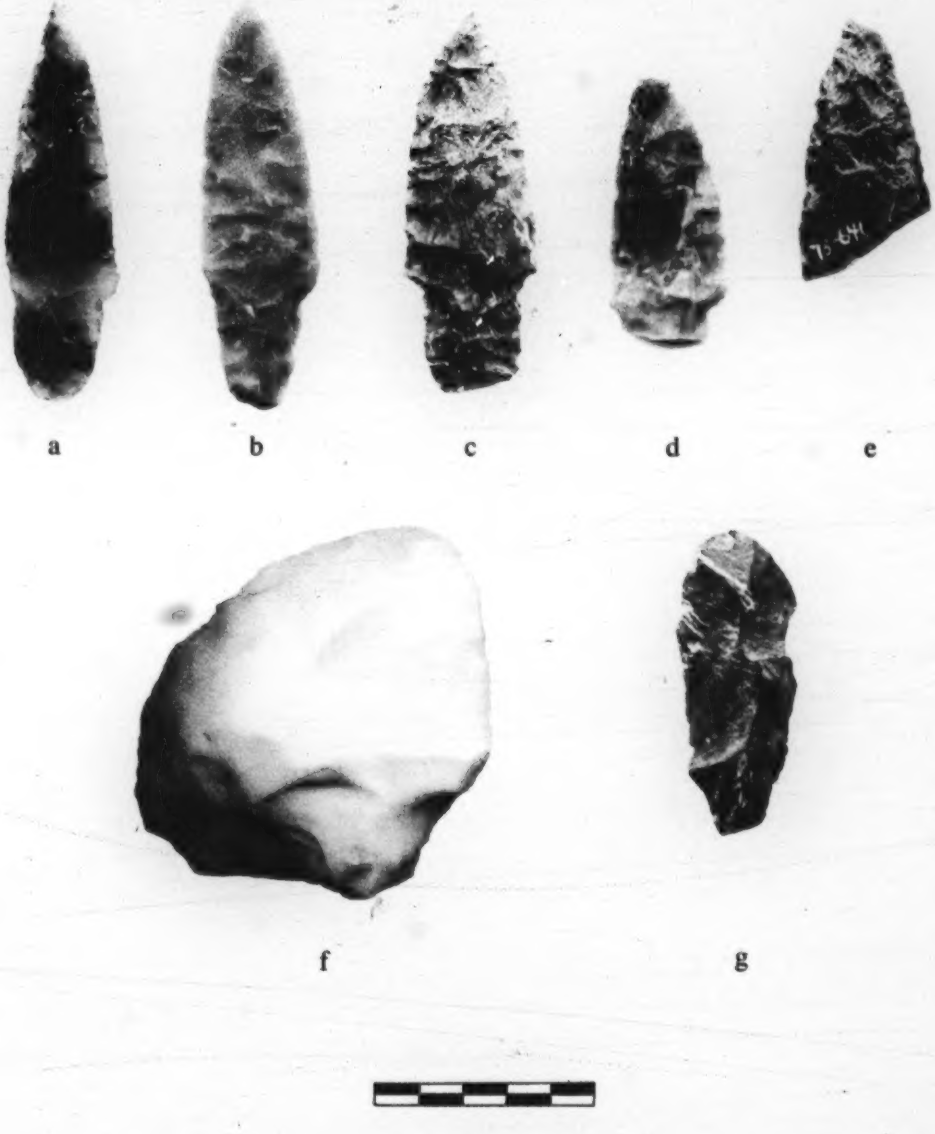

Figure 102. Images of artifacts from the A1 and A2 assemblages. Four stemmed points (a-d), a uniface (f), and a blade (g) were found in the cache pit. Artifact (e) appears to be the blade portion of a projectile point and was found in LU 4. Scale division is in centimeters.

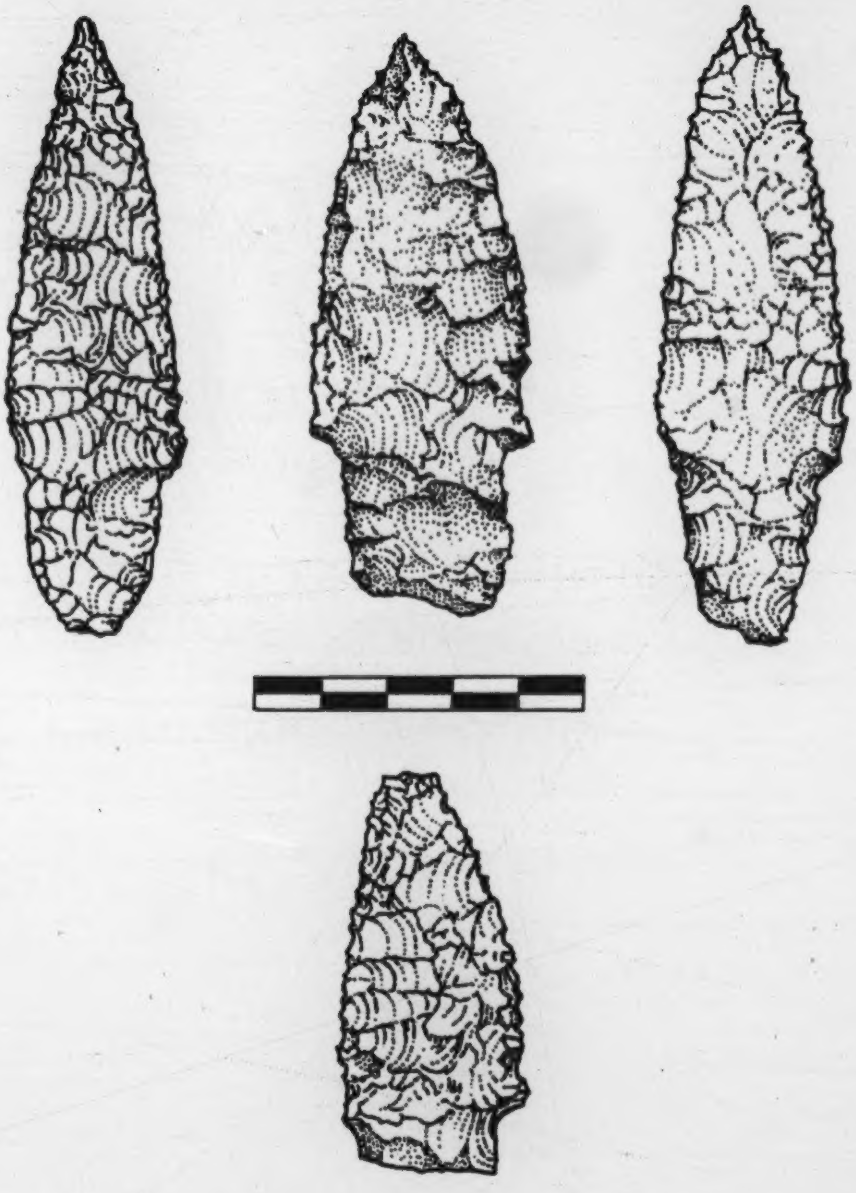

Figure 103. Illustrations of Lind Coulee points (A1 assemblage) from the cache pit, Unit A. Scale is in centimeters.

two cores, a hammerstone, and a single uniface. Together, these tools comprise what may be a basic toolkit for early hunter-gatherers that used the LSRC. Debitage was found in only slightly lower quantities within the cache pit than from LU 3. This composition of flaking debris may be an indication of purposeful disposal of debitage as the pit was backfilled. Larger proportions of chalcedony and basalt flakes were found in the cache pit than from LU 3. This pattern may be reflective of the disposal of debris from discrete knapping episodes of single material nodules rather than signifying a homogenization of LU 3 sediments during the backfilling process.

Faunal materials are unevenly distributed between LU 3 and the cache pit as well. A higher proportion of mammal bone, including an artiodactyl metapodial fragment bearing a cutmark, came from the cache pit, as did many rodent bones. Disposal of faunal materials into the cache pit probably occurred along with knapping debris, as mentioned above. The presence of organic matter in the cache pit would undoubtedly attracted scavengers such as rodents. River mussel shell and land snail shells are recovered in extremely low amounts in this component, giving little indication of their importance as a food resource during this time.

Component A2. Increased site use is seen in component A2, from the recovery of greater quantities of debitage, lithic tools, and faunal material in LU 4 (Tables 15-17). A single piece of fire cracked rock (FCR) and the appearance of fish vertebra point to a change in site use from previous levels. Although chalcedony debitage is seen in the highest number, the total weight of opal flakes is larger than all other material types. A marked increase in basalt use is seen here as well. Modified flakes comprise the largest percentage of lithic tools found in the component, while cores represent a more distant second category of formed lithic artifact. A blade fragment of what appears to be a lanceolate or stemmed point made from Salmon River Greenstone was recovered with other production debris in and around a hearth feature.

Component A3. Recovered from LU 5, component A3 is similar to the immediately preceding component A2 in its quantities of debitage, lithic tools and faunal material (Tables 15-17). Greater quantities of fire cracked rock hint at a possible change in the intensity of activities at the site. Two stemmed points comparable to Windust Phase types (Figure 104b and c) were found here, as was a fragment

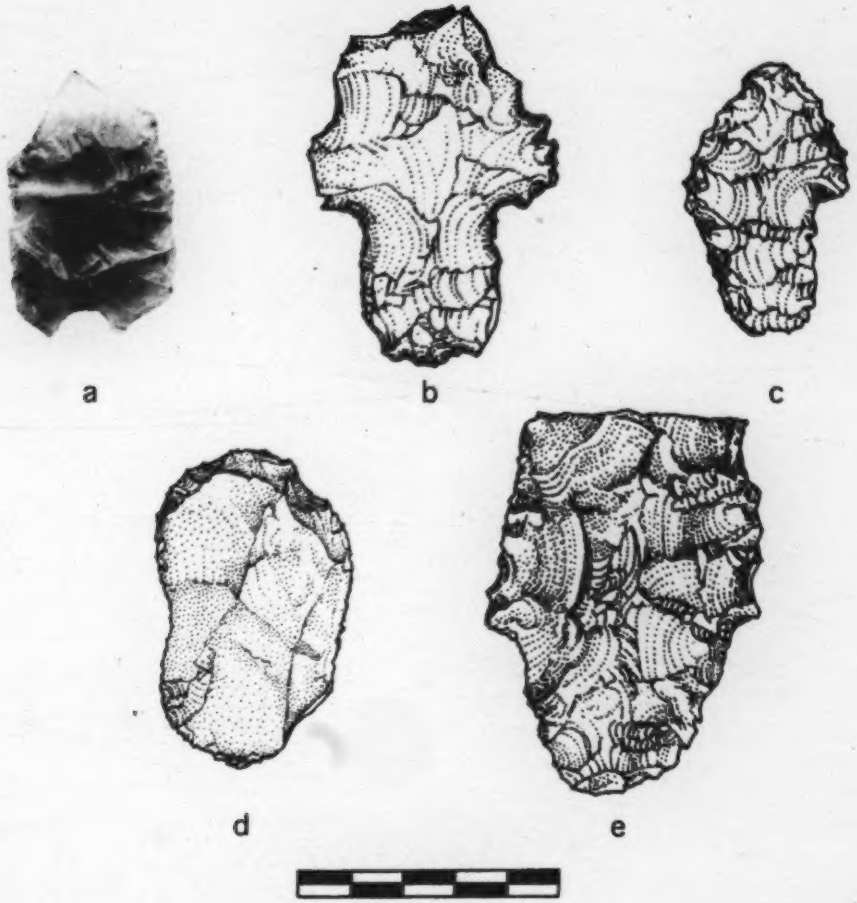

Figure 104. Artifacts from the A3 assemblage, Unit A. Scale is in centimeters.

of a large stemmed biface (Figure 104e). The large biface fragment appears as an over-sized Lind Coulee point, complete with small ear-like projections at the corners of the shoulders.

Component A4. An intensity of site use is seen in component A4 (Tables 15-17), as the total number of lithic tools recovered exceeds that of earlier components by several times, representing nearly 70% of the total tools recovered from these earlier lithostratigraphic units (LU 6 to LU 2, including the cache pit). Increases are seen in every artifact category. The use of chalcedony and opal is nearly equal in both quantity and weight, while basalt appears to be the material of choice among igenous-based rocks. Large amounts of faunal materials and FCR were found in association with hearth features and a circular pit feature (perhaps a roasting pit--see east wall in Figure 100). Interestingly, the combined shell weights of land snail and river mussel remains (19.6 g and 295.9 g respectively, for a total of 315.2 g) are close to the weight of bone (367.2 g) recovered in component A4. Fish vertebra appear in large numbers here as well (n = 126), and appear to be entirely represented by non-salmonid species. Small leaf-shaped projectile points were recovered and are similar to types grouped under the late Windust and early Cascade Phases (H.S. Rice 1965; Leonhardy and Rice 1970; D.G. Rice 1972) (Figure 105).

Unit A Chronostratigraphy

Eight AMS radiocarbon dates were produced from wood charcoal and bone collagen samples collected at the Cooper's Ferry site (Table 18). These dates were recovered throughout the stratigraphic profile, either recovered *in situ*, or in two cases, were found while screening excavated sediments. Vertically organized, the radiocarbon dates fail to produce a sequence that increases with age down-profile. This is partly due to the presence of an intrusive pit feature, which produced samples for several dates, and is partly related to problems of contamination and/or redeposition. In order to clarify the nature of Unit A chronostratigraphy, each date will be discussed in order of its vertical position.

Collagen from artiodactyl bone found between 310-321 cm below datum in the southeastern quadrant produced an AMS age of 12,020 ±170 (Beta-109971). This sample was well within the boundaries of a circular pit feature, which originated from the surface of a paleosol developed in LU 3 (beginning at 411.90 masl). Three AMS dates on wood charcoal were also collected from the pit feature in the

Site/Component	Provenience	Method	Lab Number	Material	^{14}C Age
10IH73/A5	E/413.10-413.00 masl	AMS	Beta-114952	wood charcoal	8,430 ±70
10IH73/A1/Pit	SE/410.88 masl	AMS	Beta-114949	wood charcoal	11,370 ±40
10IH73/A1	SW/411.90 masl	AMS	TO-7349	wood charcoal	11,410 ±130
SR-26-5	Paleosol 1	AMS	TO-7351	wood charcoal	10,740 ±220
SR-26-5	Paleosol 2	AMS	TO-7352	wood charcoal	11,320 ±80

Table 18. Radiocarbon ages for reliable samples from Unit A, 10IH73 and section SR-26-5. Site/Component refers to the archaeological site and component or geologic location from which a sample was recovered. Provenience refers to the quadrant and elevation of sample (in meters above sea level (masl), or soil unit associated with sample (Paleosol 1 and 2 at SR-26-5 are stratigraphic equivalents to S1 at 10IH73). ^{14}C age of samples presented in uncalibrated ^{14}C years before present.

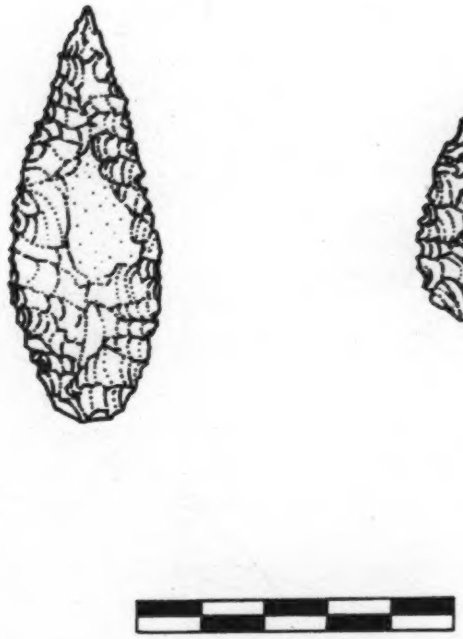

Figure 105. Illustration of leaf-shaped Late Windust/Early Cascade type lanceolate points from A4 assemblage, Unit A. Scale is in centimeters.

southeastern quadrant. In vertical order, these dates are: 8,710 ±120 BP (TO-7346) recovered from sediments between 410.90-410.80 masl; 11,370 ±40 (Beta-114949) from 410.88 masl; and 7,300 ±70 BP (Beta-114948) at 410.98 masl. Collagen from another artiodactyl bone sample found in LU 3 at 411.60 masl in the northwestern quadrant returned an AMS age of 10,050 ±180 BP (TO-7357). Wood charcoal from the surface of LU 3, at 411.90 masl, positioned in the southwestern quadrant, produced an AMS age of 11,410 ±130 BP (TO-7349). Two fragments of wood charcoal were recovered in the screen. The first was from sediments excavated between 412.40-412.30 masl (LU 6), returning an AMS age of 8,410 ±70 BP (Beta-114951). The second fragment was recovered from sediments excavated between 413.10-413.00 masl (LU 8a), with an AMS age of 8,430 ±70 BP (Beta-114952).

Of these eight dates, five are considered suspect (Table 19). Sources of contamination for bone and their effects on a sample's measured radiocarbon age are well-documented (e.g., Tamers and Pearson 1965; Stafford et al. 1988; Stafford 1994; Taylor 1994). In cases where bone collagen may be poorly preserved Stafford (1994:45) explains that corresponding AMS ^{14}C dates should be considered to provide a minimum age of the animal. Bone samples submitted for dating from Unit A were small and friable--the latter suggesting a potential loss of collagen (Hood et al. 1997). In another case, a bone sample from the cache pit feature, of slightly larger size and weight than the dated samples, failed to produce sufficient collagen for AMS dating further pointing to the state of preservation of bone in the lower deposits of the site. While the method of chemical pretreatment for AMS ^{14}C samples proposed by Stafford et al. (1988) might successfully remove all fossil bone contaminants prior to dating, this procedure was not applied to the Cooper's Ferry bone samples (Hood et al. 1997). Therefore, in consideration of these facts, the two AMS dates on bone collagen (12,020 BP and 10,050 BP) presented here may be in error and are rejected.

The two wood charcoal AMS dates of 8,710 and 7,300 BP from the pit feature in the southeastern quadrant are out of sequence, given their vertical position in the site stratigraphy. Two possible explanations may be advanced to account for this discrepency and are used to reject the two dates. First, at the time of their recovery during site excavations, ground conditions were damp, due to recent rains. The two charcoal samples were not dried prior to their submission for dating. This possibly caused the growth of spores or mold to occur on and into the matrix of the samples. Although laboratory pre-processing

Provenience	Method	Lab Number	Material	^{14}C Age	Comment
A/SE/410.98 masl	AMS	Beta-114948	wood charcoal	7,300 ±70	suspect prov.
A/NE/412.40-412.30 masl	AMS	Beta-114951	wood charcoal	8,410 ±70	suspect prov.
A/SE/410.90-410.80 masl	AMS	TO-7346	wood charcoal	8,710 ±120	suspect prov.
A/NW/411.60 masl	AMS	TO-7357	bone collagen	10,050 ±180	inadequate pret.?
A/SE/410.60-410.49 masl	AMS	Beta-109971	bone collagen	12,020 ±170	inadequate pret.?

Table 19. Cooper's Ferry radiocarbon ages from samples considered to be unreliable due to suspect provenience (suspect prov.) or inadequate pretreatment (inadequate pret.?), as explained in text. Definitions for other headings follow Table 18.

methods for wood charcoal typically remove these modern carbon sources, they may not be entirely removed. In cases where the charcoal sample is small and extensive pre-processing may dissolve all available carbon, technicians may choose to forego extra sample preparation treatments (cf., Fedje et al. 1995)--particularly when they are not alerted to the possibility of a source of contamination. Considering that the 11,370 BP charcoal sample was not oven dried prior to submission for dating, it is possible that if this sample was contaminated like the others, pre-processing at the laboratory removed all modern carbon.

The second explanation is founded in the recovery of rodent bones and teeth from the pit feature sediments. It is also possible that the wood charcoal fragments that produced younger-than-expected ages had been moved downward by the burrowing action of rodents. Clearly-defined rodent burrows were not observed in the matrix of the pit feature. This is not unusual, however, given the turbated appearance of the pit fill, which was created as excavated sediments were used to fill in the pit. In this mode of reasoning, the presence of the 11,370 BP charcoal sample is considered to be related to the reburial of the pit, which incorporated sediments from the surface of LU 3.

This latter interpretation is supported by the position of the 11,410 BP charcoal date on the surface of LU 3, located away from the pit feature. Thus, the surface of LU 3, and the associated evidence of cultural occupation, is interpreted as dating between 11,410 BP and 11,370 BP. This late Pleistocene pedogenic development, named the Rock Creek Soil (Davis n.d.) is also seen in another stratigraphic profile, designated SR-26-5, about 10.5 miles upriver from Cooper's Ferry. Two AMS dates on wood charcoal associated with thin Rock Creek Soil horizons developed on loess returned ages of 11,320 ±80 BP (TO-7352) and 10,740 ±220 BP (TO-7351) (Figure 106); the pedogenic development of the Rock Creek soil is dated between ca. 13,000 and 10,740 BP (Davis n.d.), with aeolian deposition ending soil development earlier at localities closer to the aluvial floodplain. Oxygen-18 compositions in soil carbonates from Rock Creek Soil horizons show the same pattern of increased aridity and temperature prior to 11,000 BP, followed by an abrupt shift to cooler and more mesic conditions after 11,000 BP observed at the Cooper's Ferry site. The isotopic stratigraphy of soil carbonate δ^{18}O at SR-26-5 provides an independent means of correlating stratigraphic units (Jansen 1989) and firmly establishes a pre-11,000 BP age for LU 3.

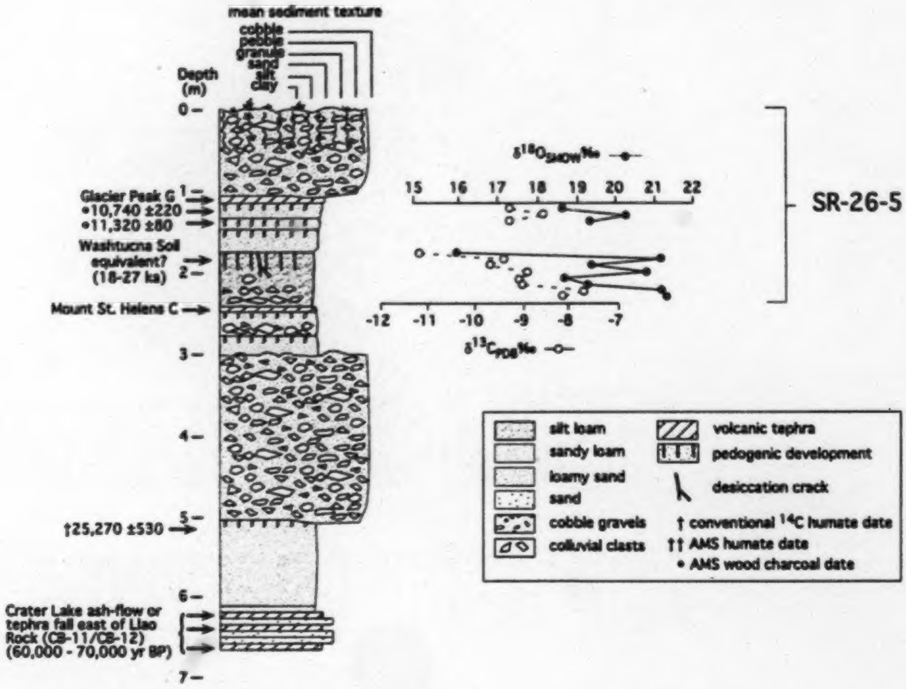

Figure 106. Stratigraphic profile of SR-26-5, showing the position of AMS dates, paleosols and stable isotope geochemistry of soil carbonates.

Establishing the antiquity of the lower Cooper's Ferry occupation containing Lind Coulee points might be made through a reconsideration of the age of the Lind Coulee site itself. Daugherty's (1956) excavations at the Lind Coulee site in southeastern Washington produced the initial and most well-known discovery of Lind Coulee projectile points. Although several radiocarbon dates from the Lind Coulee occupation returned ages between ca. 8,500 and 9,400 BP, the accuracy of these ages are considered suspect, due to possible radon contamination (Irwin and Moody 1978:226). The earliest occupation with Lind Coulee points is bracketed, stratigraphically speaking, below a Mount St. Helens set J tephra layer, and above a layer of Glacier Peak tephra (Irwin and Moody 1978). Glacier Peak tephra was dated to ca. 11,200 BP (Mehringer et al. 1984), whereas, in the 1970s, a late eruption of Mount St. Helens set J was thought to date to ca. 8,900 BP (Mullineaux et al. 1975); thus providing another supporting line of evidence for the suspect radiocarbon ages. Mullineaux (1986:23) revises his earlier position on the younger limiting age of the Mount St. Helens set J tephra, suggesting now that all eastward-extending set J layers should date from a period slightly younger than 11,000 BP to ca. 12,000 BP. Based on this revision, the early occupation at the Lind Coulee site can be argued to date between ca. 11,000 and 11,250 on the basis of site tephrostratigraphy. Reconsidering the dating of the Lind Coulee site is important, since Lind Coulee stemmed point technology is argued as a evolutionary ancestor to Windust Phase stemmed points in the Plateau (Leonhardy and Rice 1970; D.G. Rice 1972). The strength of this argument was questioned on the basis of Irwin and Moody's (1978) dating, which failed to show Lind Coulee points to be a temporal predecessor to Windust (e.g., Carlson 1983; Beck and Jones 1997; Lyman 2000). Considering Mullineaux's (1986) revised age for set J, the antiquity of the Lind Coulee site is placed in a different light. By establishing the early occupation at the Lind Coulee site before 11,000 BP, additional support is provided for the late Pleistocene-age radiocarbon dating of Lind Coulee points at Cooper's Ferry.

The 8,410 BP AMS date on wood charcoal is thought to be vertically displaced for several reasons. First, the closeness of temporal overlap with the 8,430 BP date located nearly 70 cm above in the profile is suspect. If we accept that the 70 cm of geologic materials between the two dates were deposited on an extremely short time scale, then the presence of stratified cultural occupations (complete with hearth features) within these sediments must be accounted for. Furthermore, important changes in lithic technology were occuring during the time that LU 3 was being deposited. The discovery of a diagnostic triangular-bladed stemmed projectile point at the bottom of LU 3 with its associated date of 8,410 BP is suspect. Identical point forms are dated at the Hatwai site to the north between 9,000 and 10,800 BP (Ames et al. 1981; Sanders 1982) and in association with the Buhl Burial of southern Idaho, which was dated to 10,700 BP (Green et al. 1998). The position of the 8,430 BP wood charcoal AMS date is reasonable, given the presence of diagnostic Cascade artifacts types (Leonhardy and Rice 1970) and is not questioned at this time.

A Synthesis of Early Cultural Stratigraphy

Stratigraphic descriptions and profiles provided by Bulter (1969) and Murphy et al. (1976) are correlated with Unit A deposits (Table 20, Figure 107). Correlating geologic units between Unit A and Butler's Trench A provides the means for building a synthesis of cultural stratigraphy at Cooper's Ferry (Figure 108). Eight cultural components are defined on the basis of technological affinities and stratigraphic divisions, which are named Cooper's Ferry (CF) 1 through 8 (e.g., CF3, CF4). Grouping the frequencies of projectile point types recovered from both Unit A and Trench A (Butler 1969) allows for the presentation of a percentage-based seriation plot (Figure 109), which shows a clear pattern of replacement among stemmed, lanceolate, and notched point types through time.

Paleoenvironmental Context of Early Prehistoric Occupation

Geomorphic Processes

Site formation appears to be dominated by alluvial and aeolian depositional processes. Butler (1969) notes the occurrence of angular "colluvial" gravels present at the surface of the basal gravel unit (Layer 11 in Trench A). This is to be expected, given the closeness of the canyon wall to the site. Butler characterizes many stratigraphic units as "dune" deposits; no justification for this genetic identification is provided, however, apart from noting a dominantly sandy texture throughout the profile of Trench A. At excavation Unit A, LU 4 and LU 3 are intepreted as aeolian in origin, while LU 8a through LU 5, and LU 2 are interpreted as alluvial sediments.

Butler (1969)	
1.	backdirt from 1962 excavation
2A.	compacted, dark brown loamy sand with increased silt
2B.	same as 2A except more compact
3.	compacted, brown, loamy sand with small, subangular rocks
4.	fine, grey sand with lime veins
5.	fine, light brown, silty sand; calcium carbonate present
6.	very fine greyish-brown sand; diffuse, wavy lower boundary
7.	moderately compacted, extremely fine grey sand; capillary movement of water evident in the layer
8.	very fine, yellow-brown silty sand with more calcium carbonate than upper layers; wavy diffuse lower boundary
9.	loosely compacted, brownish-grey sand subrounded basalt cobbles with many lime veins
10.	moderately (plus) medium to large cobbles with carbonate coating and cement; loose fine to coarse, subangular basalt gravel mixed with well rounded cobbles underlies.

Murphy et al. (1976)	
1.	yellowish dark brown sandy loam
2.	yellowish brown sandy silt
3.	dark brown sandy silt
4.	grayish brown very fine sand
5.	yellowish brown very fine sand
6.	light yellowish brown very light sand
7.	yellowish brown very fine sand
8.	grayish brown medium fine sand
9.	very fine yellowish brown sand
10.	grayish brown medium fine sand
11.	yellowish brown very fine sand
12.	medium fine grayish brown sand
13.	yellow brown fine sand
14.	medium fine grayish brown sand
15.	yellow brown fine sand
16.	yellow brown very fine sand
17.	rock bottom with rounded to

Table 20. Stratigraphic descriptions from Butler (1969) and Murphy et al. (1976).

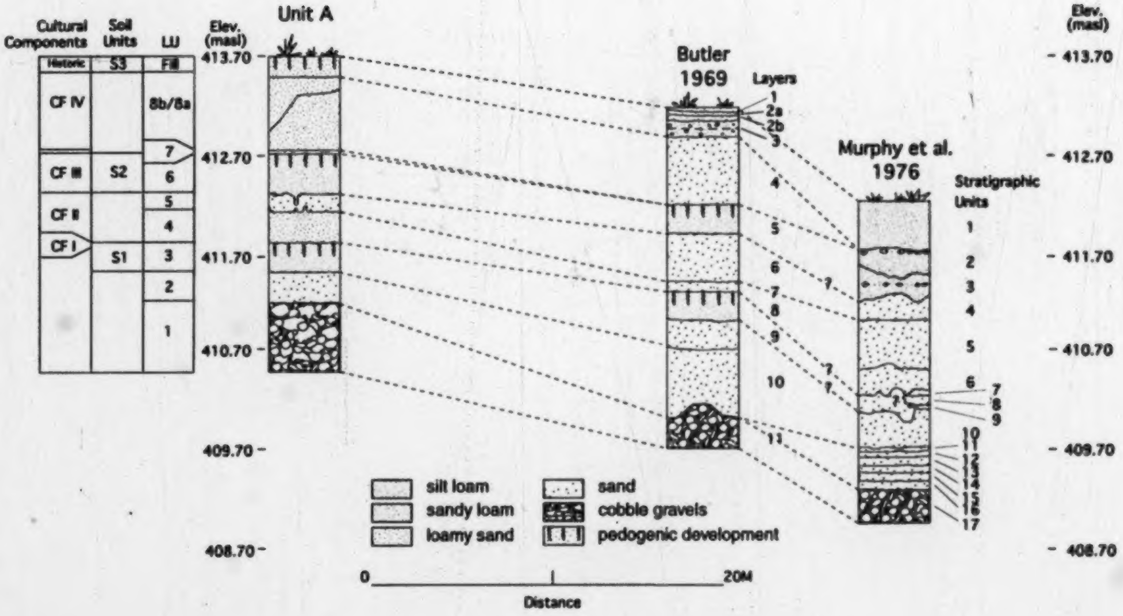
Cultural Components
Soil Units
LU
Elev. (masl)
Historic
S3
Fill
CF IV
8b/8a
7
CF III
S2
6
5
CF II
4
CF I
S1
3
2
1
413.70
412.70
411.70
410.70
409.70
408.70
Unit A
Butler 1969
Layers
1
2a
2b
3
4
5
6
7
8
9
10
11
Murphy et al. 1976
Stratigraphic Units
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
?
Elev. (masl)
silt loam
sandy loam
loamy sand
sand
cobble gravels
pedogenic development
0
20M
Distance

Figure 107. Correlation of Unit A stratigraphy with geologic units reported by Butler (1969) and Murphy et al. (1976).

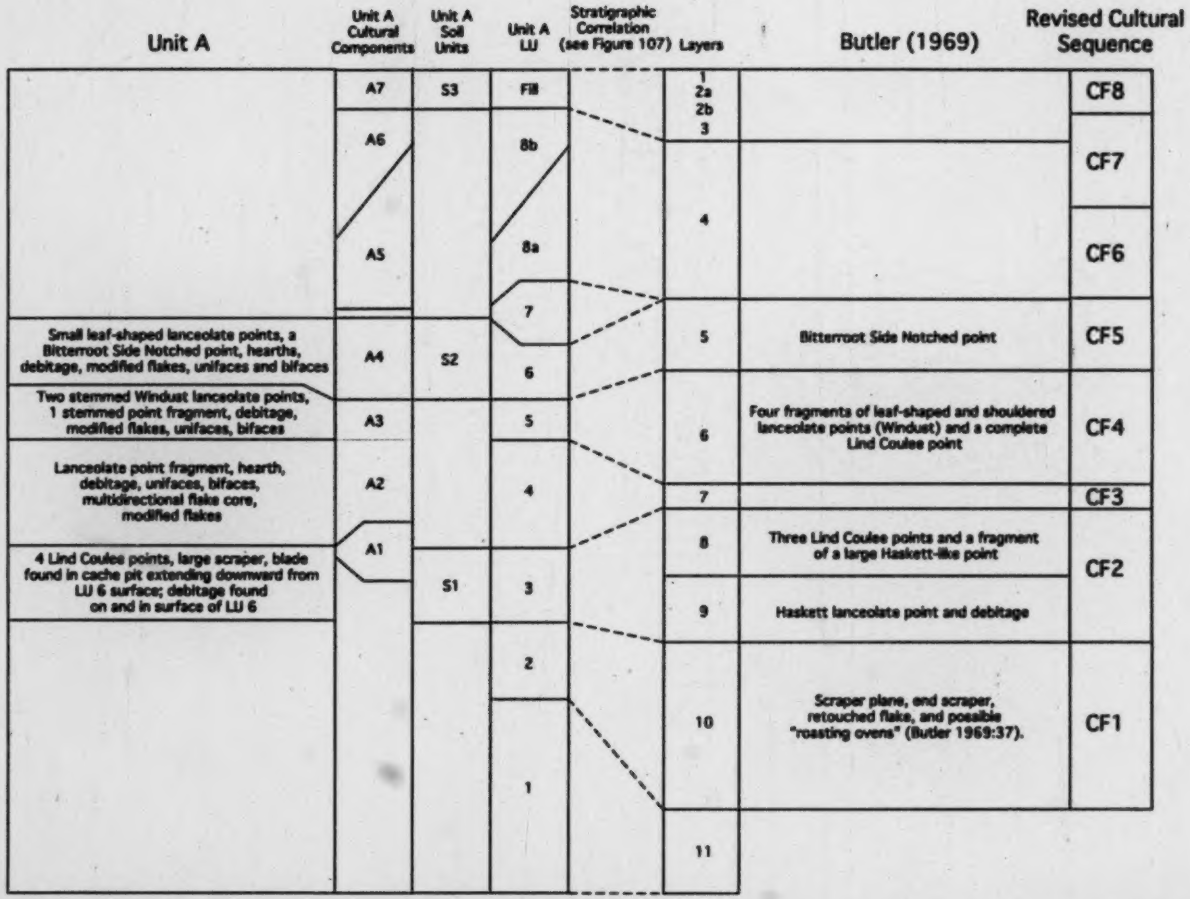
Unit A
Unit A Cultural Components
Unit A Soil Units
Unit A LU
Stratigraphic Correlation (see Figure 107)
Layers
Butler (1969)
Revised Cultural Sequence
Small leaf-shaped lanceolate points, a Bitterroot Side Notched point, hearths, debitage, modified flakes, unifaces and bifaces
Two stemmed Windust lanceolate points, 1 stemmed point fragment, debitage, modified flakes, unifaces, bifaces
Lanceolate point fragment, hearth, debitage, unifaces, bifaces, multidirectional flake core, modified flakes
4 Lind Coulee points, large scraper, blade found in cache pit extending downward from LU 6 surface; debitage found on and in surface of LU 6
A7
A6
A5
A4
A3
A2
A1
S3
S2
S1
Fill
8b
8a
7
6
5
4
3
2
1
1
2a
2b
3
4
5
6
7
8
9
10
11
Bitterroot Side Notched point
Four fragments of leaf-shaped and shouldered lanceolate points (Windust) and a complete Lind Coulee point
Three Lind Coulee points and a fragment of a large Haskett-like point
Haskett lanceolate point and debitage
Scraper plane, end scraper, retouched flake, and possible "roasting ovens" (Butler 1969:37).
CF8
CF7
CF6
CF5
CF4
CF3
CF2
CF1

Figure 108. Synthesis of cultural stratigraphy at Cooper's Ferry, as established by geologic correlation between Unit A lithostratigraphic units (Unit A LU) and pedostratigraphic units (Unit A Soil Units), and Trench A Layers (Butler 1969). Cultural materials contained in corresponding geologic deposits are grouped into eight Cultural Synthesis units (e.g., CF3).

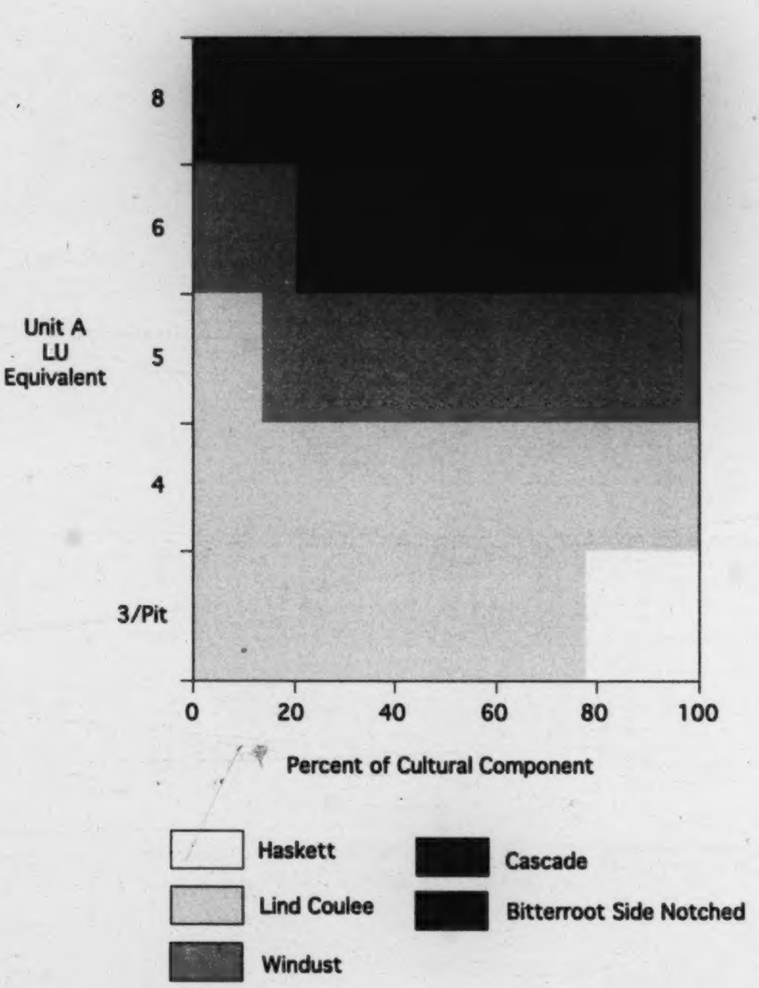

Figure 109. Percentage-based seriation plot showing the frequency of projectile point styles recovered from Unit A and Trench A (Butler 1969). Correlation of geologic deposits containing the points follows that presented in Figure 108, and forms the primary basis for organizing point styles in a chronological sequence at Cooper's Ferry. Since the cache pit extends downward from the surface of LU 3, associated point styles in both deposit and pit feature are grouped here.

Paleoclimatic Conditions

Records of stable isotope geochemistry from soil carbonate and mussel shell carbonate samples collected from the Cooper's Ferry site are used to build a proxy record of paleoclimatic conditions in the LSRC (Figure 97). The *M. falcata* $\delta^{18}O$ record (Davis and Muehlenbachs 2001) includes five data points reflecting increased aridity at ca. 11,500 BP, 10,750 BP, 10,100 BP, 8,950 BP, and 7,800 BP. Conditions drier than today are projected for the entire period between 11,000 and 10,000 BP. Four periods of increased humidity are estimated at 11,800 BP, 11,200 BP, 9,500 BP, and between 8,500 and 8,100 BP. Several rapid, broad fluctuations from wet to dry conditions are seen across the Pleistocene-Holocene boundary.

Paleovegetation

Close examination of the $\delta^{18}O$ and $\delta^{13}C$ stratigraphy reveals an asynchronous pattern of isotopic composition through time (Figure 97). Variation in $\delta^{13}C$ follows $\delta^{18}O$ trends throughout the profile at an offset pattern. For example, $\delta^{18}O$ values rise and fall during the deposition of LU 4, only to rise and fall again during the deposition of LU 5 and LU 6. This sequence in $\delta^{18}O$ fluctuation is intepreted as reflecting two periods of rising temperatures and aridity, each followed by excursions to cooler and less arid conditions. Carbon-13 compositions in the same lithostratigraphic units reveal a similar but asynchronous pattern of rising and falling compositions, which are interpreted to reflect changes in C_3 plant percentages at the site. This lead-lag signature is thought to be related to the effects of a delayed response in riparian hydrology to the onset of changing climatic conditions (Davis et al. n.d.).

Unlike plant populations on well-drained canyon slopes, drought-sensitive vegetation is able to survive periods of increased aridity in the riparian zone as long as alluvial systems can provide ample moisture for growth. During extended periods of increased aridity, however, changes in alluvial hydrology are expected to occur eventually. The delayed shift in $\delta^{13}C$ seen in the stratigraphic record of 10IH73 is thought to reflect the vegetative response to a retarded hydrological shift following increased aridity. Even after climatic conditions return to more mesic levels, vegetative replacement in the riparian zone is not expected to occur immediately and may be delayed by competition between plant species for a short time.

Carbon-13 compositions and C_4 plant populations are relatively high during most of the late Pleistocene to early Holocene. A significant increase in C_3 plants occurs during the deposition of LU 5 and LU 6 and is thought to represent the expansion of more mesic riparian vegetation following a shift towards cooler temperatures, increased preciptiation, and greater floodplain alluviation in the LSRC.

Faunal Record

Fish bones recovered during excvations at Unit A varied in quantity throughout the stratigraphic sequence (Figure 97). When compared against other stratigraphic data, fish remains are most abundant during the deposition of LU 6, which is associated with increased aridity in reflected *M. falcata* shell $\delta^{18}O$, soil carbonate $\delta^{18}O$ and with increasing proportions of C_3 plants in the riparian zone. After this maximum value in LU 6, fish remains decrease in abundance throughout the remainder of the profile at a much reduced frequency. The reasons for the variability in the frequency of fish remains at Cooper's Ferry might not entirely reflect changes in aquatic habitats. Given a larger sample size, patterns of faunal remains might reflect different quantities, exposing the correlations reported here as coincidental. Alternatively, the increased abundance of fish remains may actually represent an indication of aquatic habitat productivity for non-anadromous fishes in the LSRC; coinciding evidence of warmer climates, floodplain stability, and increased riparian vegetation productivity adds strength to such an interpretation.

Discussion

Implications of the Cultural Sequence

The discovery of a continuous sequence of cultural occupation beginning at 11,410 BP not only provides an early radiometric context for human occupation in the southern Columbia Plateau region, but helps to clarify the early cultural sequence of the Pacific Northwest. The discovery of a continuous evolutionary progression of non-fluted technology beginning at a period contemporaneous (at minimum) with the appearance of Clovis fluted point technology, points to the presence of greater technological diversity in Pleistocene-age North America than traditionally suspected.

The dating of stemmed points at Cooper's Ferry calls for a reconsideration of long-held models of early prehistory in the Pacific Northwest and support hypotheses advanced by Bryan (1977, 1980, 1988, 1991) regarding the age and nature of the Western Stemmed Tradition. There is disagreement as to whether a temporal sequence and evolutionary affinity exists between fluted and stemmed point technologies in the Pacific Northwest as in other regions, like the Plains and Southwest (e.g., Frison 1978, 1991; Frison and Stanford 1982). Considering the chronology at the Cooper's Ferry site, a resolution to this debate appears to be emerging. A clear sequence of technological continuity appears to exist for early stemmed point technological traditions like Lind Coulee and Windust in the Pacific Northwest, rather than between fluted and later unfluted traditions.

Butler's discovery of a scraper plane, an end scraper, a retouched flake and multiple "dish-shaped depressions in the surface of the terrace" that, "suggest roasting ovens" (Butler 1969:37) is difficult to evaluate on the basis of the evidence at hand. This cultural component was not encountered in Unit A, nor in D.G. Rice's excavation unit. During the time of Butler's basal occupation, the bank of the Salmon River was apparently close to the position of Trench A. The stratigraphic perspective shown in Figure 107 suggests the presence of a gently sloping sand-covered gravel bar. It may be possible that Butler's earliest occupation, discovered only in in Trench A, was limited to areas closer to the bank of the Salmon River. If the stratigraphic sequence is correct, as shown in Figure 108, Butler's earliest occupation would predate the 11,390 BP mean date of the two AMS dates from wood charcoal associated with LU 3 and the cache pit fill in Unit A. Additional excavation is clearly required to clarify the stratigraphic relationship between Unit A and Trench A, particularly given the potential for the presence of an even earlier cultural occupation at the site.

A Question of Caches

Caches of finely-made projectile points, bifaces, and rods of bone and ivory are known from several sites in western North America (Figure 94). While the purpose of these caches is unclear, Meatte (1998) suggested that two categories of Clovis caches may exist in western North America: the first associated with burials, which are not intended to be recovered; and the second representing equipment caches, which are to be recovered for future use. Only the Anzick site (Lahren and Bonnichsen 1974) of Montana is seriously considered as representing a burial, although uncertainties are raised (Haynes 1980). Other Clovis caches in western North America are likely not associated with burials, including the Simon (Butler 1963), Richey-Roberts (Mehringer and Foit 1990), and Fenn (Frison and Bradley 1999) sites; and most likely represent equipment caches.

Unlike the western Clovis caches, it is clear that the stemmed points found at the Cooper's Ferry site were placed together in a pit, underscoring the formal and purposeful nature of their interment. Because of the lack of association with human skeletal remains and the absence of ochre, the Cooper's Ferry cache is best characterized as the storage of equipment for recovery at a future time; and not intended as a burial offering. Of all the early caches in the Far West, the Cooper's Ferry cache is the only one associated with chronometric dates of a Pleistocene age. Given its age, it is unclear how the Cooper's Ferry cache may relate to other Clovis caches in the Far West. The creation of an equipment cache in the LSRC may represent an aspect of a logistical strategy for hunting large game during the late Pleistocene. Caches likely provided an effective means of interacting with spatial and temporal variability of resources during the change from glacial to interglacial environments. The strategic placement of equipment caches across the landscape may be a common, but rarely seen aspect of a highly mobile lifeway, where stores of finely-made tools could be retrieved in times of need. Thus, the discovery of the Cooper's Ferry cache may help to clarify patterns of settlement and mobility among early hunter-gatherers in the Pacific Northwest.

Evolution of Riparian Environments: Implications for Hunter-Gatherers

The character of riparian environments apparently changed greatly through time, as reflected in the stratigraphic record at 10IH73. During the close of the Pleistocene, the LSRC appears to experienced hot, dry and dusty summers and cold, dry winters. Across the Pleistocene-Holocene transition, climatic conditions and ecological indicators reflect conditions that rapidly changed from hot and dry to cool and moist. Despite the instability of environmental conditions, geologic evidence shows the development of an alluvial floodplain corresponding with increasing frequencies of C_3 plants. This alluvial context represents a significant shift in riparian ecology by the early Holocene period. Because of the influence of an earlier landslide that greatly changed the fluvial structure of the LSRC (Davis n.d.), low-energy floodplain deposition occurred during the LP-EH transition. This alluviation was likely aided by drier climatic conditions and shifts in canyon slope vegetation (Davis et al. n.d.) that enhanced erosional inputs to the Salmon River. Thus, while climates ranged widely across the LP-EH transition, a lush, oasis-like riparian ecosystem was developing in the LSRC. It is also apparent that the richness of this riparian context did not go unnoticed by early hunter-gatherers. The deposition of low-energy floodplain sediments at 10IH73 corresponds with marked changes in human behavior, as reflected in the intensification of site use, changes in lithic tool assemblages and resource extraction from the canyon. These environmental changes are seen as the source of opportunity for early hunter-gatherers, instead of the origin of forcing mechanisms for culture change. Our real interest lies in elucidating the manner in which people made decisions to use these new conditions and the consequences of these choices.

Conclusions and Future Recommendations

Archaeological and geoarchaeological investigations at the Cooper's Ferry site produced the some of the earliest radiometrically-dated evidence of human occupation in the southern Plateau region, extending the prehistory of the LSRC into the late Pleistocene. The discovery and dating of an early cache of Lind Coulee points presents wide-reaching implications for Plateau prehistory. In light of Mullineaux's (1986) reassessment of the age limits on the Mount St. Helens Set J tephra, and the radiocarbon dates presented here from the Lind Coulee point cache and LU3 paleosurface, the antiquity of the Lind Coulee site should be reconsidered. This perspective breathes new life into the hypothesis that the evolution of stemmed projectile point forms occurred exclusively through the differential replication of non-fluted forms.

Paleoenvironmental proxy records show how the interplay between changing climates, hydrological conditions, and geomorphic processes contributed to unstable late Pleistocene to early Holocene ecological conditions in the LSRC. Although climatic conditions reflect rising aridity and temperatures in the canyon after 9,000 BP, riparian vegetation responds in a non-linear manner, which is seen to reflect phreatophytic plant adaptation to asynchronous changes in floodplain hydrology. The stability and expansion of riparian ecosystems in the study area after 9,000 BP probably provided an attractive environmental buffer for hunter-gatherers against early Holocene xerification of canyon slopes and adjacent uplands.

Because our research plan called for only limited excavations during our 1997 investigations at Cooper's Ferry, questions remain unanswered by the current data. Future investigations at the site should address several important issues. First, stratigraphic excavations should be conducted, given the clearer perspective on the geologic sequence of the site, in order to carefully test the cultural-stratigraphic relationships presented in this work. Second, in order to firmly establish the temporal boundaries between archaeological components, efforts must be made to strengthen and clarify the chronostratigraphic framework established here. The process of careful three-dimensional mapping of artifacts must be continued in order to gain further insight into site-level activities. Lastly, archaeological and geoarchaeological research specifically directed towards the investigation of late Pleistocene-age deposits in the Plateau must increase in order to resolve many of the questions raised here.

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CHAPTER EIGHT

LOWER SALMON RIVER CULTURAL CHRONOLOGY: A REVISED AND EXPANDED MODEL

A version of this chapter by L.G. Davis was submitted for publication in Northwest Anthropological Research Notes.

Introduction

Thirty-three years after Butler wrote that archaeological work in Idaho was still in its pioneering stages (Butler 1968:16), detailed culture history models are still absent from significant portions of Idaho. Butler's statement characterized the situation in 1996 when a cooperative project was initated between the Department of Anthropology, University of Alberta and the Cottonwood Field Office, Bureau of Land Management, which sought to investigate the archaeology and geology of the Lower Salmon River Canyon (LSRC) (Figure 110). Although Butler himself had conducted excavations in the area proposed for study, the prehistory of the LSRC remained incomplete. New information from seven sites excavated in the canyon between 1997 and 2000 provided a means of clarifying and expanding upon Butler's original model of culture history. In order to present a new model of LSRC culture history, Butler's model will be briefly reviewed in order to establish a historic context for local research; next, the results of recent investigations are summarized into a revised model of culture history; lastly, the implications of the cultural sequence presented are discussed as they provide important implications for regional prehistory, and may help resolve long-standing debates on the early prehistory of the Pacific Northwest.

Previous Research

Old Cordilleran Culture

In 1961, Butler synthesized archaeological evidence of early Pacific Northwest occupation and formalized his earlier thoughts (Butler 1958a, 1959) into a model that sought to explain the origin of human entry, cultural adaptation and dispersal throughout the region. Under this model, peoples bearing a lithic technology of leaf-shaped lanceolate projectile points (i.e., "Lerma-like" (MacNeish 1959:5); cf. Leonhardy and Rice 1970)), edge-ground cobbles, and simple chopping, scraping and cutting tools entered the Pacific Northwest along the Cordilleran mountain chain by 12,000 to 13,000 yr BP and spread throughout the region. Subsistence adaptations were generalized throughout the region, with an emphasis on local abundances of game and/or fish populations; however: "Extensive use of fish does not appear to have become a universal phenomenon in the culture; indeed, depending on the nature of the local ecology,

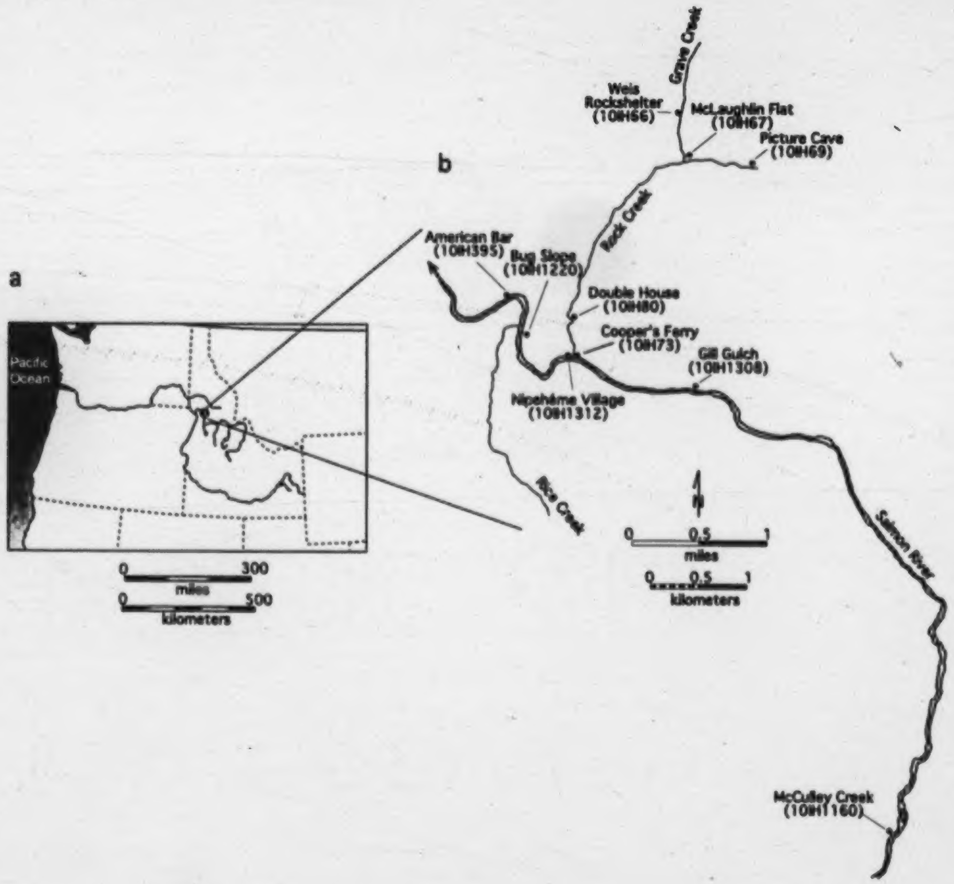
a
Pacific Ocean
0
300
miles
0
500
kilometers
b
Grave Creek
Weis Rockshelter (10IH66)
McLaughlin Flat (10IH67)
Picture Cave (10IH69)
Rock Creek
American Bar (10IH395)
Bug Slope (10IH1220)
Double House (10IH80)
Cooper's Ferry (10IH73)
Gill Gulch (10IH1308)
Nipehéme Village (10IH1312)
Rice Creek
N
0
0.5
1
miles
0
0.5
1
kilometers
Salmon River
McCulley Creek (10IH1160)

Figure 110. (a) Map showing location of the Lower Salmon River Canyon study area in the Pacific Northwest and (b) archaeological sites mentioned in text.

the economy of the Old Cordilleran Culture remained essentially land-oriented for a considerable length of time" (Butler 1961:66).

For a time, this model was advanced as a means of explaining the origins of early archaeological cultures in the Far West and beyond. Butler argued that the occurrence of leaf-shaped lanceolate points with simple lithic technology and generalized hunter-gatherer-fisher subsistence adaptations seen from the Northwest Coast into Latin America was evidence of the rapid spread of the Old Cordilleran Culture in the New World. Later, where this cultural tradition came into contact with traditions from other regions, technological changes and additions were seen to alter the archaeological pattern somewhat (e.g., the inclusion of Cold Springs side notched points is thought to represent evidence of interaction with Swanson's Bitterroot culture sphere of southeastern Idaho; modification and change is also cited as a result of contact with the Desert Culture complex (Butler 1961:70)).

After the publication of his Old Cordilleran Culture model (Butler 1961), Butler sought out evidence to test his ideas at sites in the LSRC (Butler 1966:23). The discovery of a long record of cultural occupation at the Weis Rockshelter site beginning with leaf-shaped lanceolates was taken to support his model. In 1961-1962 and in 1964, Butler conducted excavations at the Cooper's Ferry site (10IH73), discovering cultural occupation containing large stemmed and lanceolate points in association with geologic deposits suspected as being late Pleistocene to early Holocene in age (Butler 1969). Two possible explanations were offered for the discovery of this early cultural component at Cooper's Ferry that could not be attributed to the Old Cordilleran Culture. First, the points were classified as Plains in origin and their presence in the Salmon River Canyon was seen as the result of a "momentary intrusion of Early Big Game Hunters" (Butler 1962:79) and that "...Cascade points were still the earliest type to be found in the region" (Butler 1969:35). Secondarily, in light of Richard Daugherty's (1956) work at the Lind Coulee site of eastern Washington, which produced what was interpreted at the time as one of the earliest cultural occupations in the Pacific Northwest, Butler's (1969:35) discovery of Lind Coulee points at Cooper's Ferry as is explained as, "a co-tradition of the Old Cordilleran culture in the Pacific Northwest... (Butler 1962:63-64)."

In the face of a growing database that placed the Cascade type much later in time than he first hypothesized (e.g., Leonhardy and Rice 1970), Butler abandoned the use of the Old Cordilleran Culture by the late 1970s, whereafter he presents models of Upper Snake and Salmon River prehistory in a format that includes the classic Clovis-Folsom-Plano sequence of big game hunters as the basal cultural traditions (Butler 1978).

Butler's Lower Salmon River Canyon Culture History Model

Butler conducted archaeological excavations at five sites in the LSRC between 1961 and 1964, including Weis Rockshelter (10IH66), McLaughlin Flat (10IH67), Picture Cave (10IH69), Cooper's Ferry (10IH73) and Double House (10IH80). The results of this work were published in several reports and monographs (Butler 1962, 1966, 1968, 1969). Radiocarbon dates from Weis Rockshelter and Double House span the period 7,340 ±140 BP to 4,650 ±70 BP and 2,040 ±190 BP to 0 ±57 BP, respectively. On the basis of this work, Butler (1968:98-100) developed a culture history model in the tradition of Willey and Phillips (1958), which included four cultural phases spanning 7,400 years, briefly summarized below.

Craig Mountain Phase (7,400 - 3,500 yr BP)

Characteristic artifacts of this period include edge-ground cobbles, antler wedges and leaf-shaped lanceolate points of the Cascade type (Butler 1966:Figure 26, Butler 1968:Figure 22; Leonhardy and Rice 1970). Subsistence patterns include "extensive" use of freshwater mussels and deer; limited evidence of possible bison hunting is provided by the discovery of teeth from two individuals in Weis Rockshelter (Butler 1968:100). Butler combined the undated finds from Cooper's Ferry into the Craig Mountain Phase, leading him to conclude that the assemblage represented, "a brief intrusion of early Big-game Hunters into the Clearwater Plateau just after the onset of the Altithermal conditions in the Columbia Basin" (1968:100).

Grave Creek Phase (3,500 - 2,100 yr BP)

Butler defines this phase primarily on an increase of Bitterroot Side-notched points (Butler 1966:Figure 27) and a declining number of Cascade points, which are confined to the earlier part of this period. Milling stone technology also appears during this phase, while edge-ground cobbles decline in number.

Rocky Canyon Phase (2,100 - 600 yr BP)

The appearance of semisubterranean housepit structures and smaller corner-notched points (Butler 1966:Figure 27) are important additions to the archaeological record characterizing the Rocky Canyon Phase. Bitterroot side-notched points are seen in much reduced numbers than in previous phases. A variety of grinding and pounding stone tools, thought to be used for processing plant foods, increase during this time. Large game, including deer, elk, and mountain sheep was hunted, while the collection of river mussels appears to remain an important staple.

Camas Prairie Phase (600 - 150 yr BP?)

This last phase is correlated with ethnographic patterns of Nez Perce material culture and include "circular mat lodge and parallel-sided, round-ended community lodge" (Butler 1968:99, cf. Butler 1966:Figure 28) structures, hopper mortar bases (Butler 1966:Figure 13), small basal or corner-notched points (Columbia Valley points (Butler 1966:Figure 27)), Desert Side-Notched points, gaming implements and antler wedges. Schwede (1966) cites ethnographic records of the Grave Creek-Rocky Canyon area as home to a band of Nez Perce named the Nipehéme, which was reportedly derived from the larger Clearwater River valley group.

Investigations During the Last 25 Years

Apart from the work of Butler, previous archaeological excavations conducted along the Lower Salmon River were restricted to small testing projects, which provide little information to clarify or test Butler's culture history model. Oswald (1975) compiled information on a late prehistoric occupation at 10IH94 near Slate Creek. Excavations at Russel Bar (10IH58) by Markos et al. (1990) revealed a cultural component dated at 300 ± 60 yr B.P. (Beta-34369) and 1,330 ± 100 yr B.P. (Beta-34370). Miss (1990) conducted limited archaeological testing at Butcher Bar, producing two radiocarbon dates of 630 ± 90 yr B.P. (Beta-33442) from site 10IH1908 and a date of 1,400 ± 90 yr B.P. (Beta-33443) from 10IH1957. Sappington et al. (1995) excavated a housepit site (10IH369) situtated on a terrace immediately upstream of

Island Bar, near the town of Riggins. The housepit feature was dated at 920 ± 45 yr B.P. (Tx-8236), while bulk humates from a lower paleosol with cultural materials returned dates of 2,395 ± 73 (Tx-8273) and 3,695 ± 55 yr B.P. (Tx-8238). Davis et al. (1995) conducted archaeological excavations at 10IH42, which is contained along the length of Island Bar; no diagnostic artifacts were recovered, however, nor were any chronometric assays made.

Sites Investigated Between 1997 and 2000

Seven sites were investigated during the 1997, 1999, and 2000 field seasons by the University of Alberta, including: Cooper's Ferry (10IH73), American Bar (10IH395), Bug Slope (10IH1220), McCulley Creek (10IH1160), Nipehéme Village (10IH1312), and Rock Creek Bridge (10IH2491); the Gill Gulch site (10IH1308) was tested by archaeologists from the Cottonwood, Idaho office of the Bureau of Land Management (BLM) in 1997 (Dickerson 1997), and also excavated by the University of Alberta in 2000. On the basis of results from these more recent archaeological investigations, new information is available to evaluate and revise Butler's (1968) culture history model. Of greatest importance is the discovery of late Pleistocene- and early Holocene-age cultural components, which are underrepresented in Butler's model.

Revised Culture History Model

Two new phases are proposed here, on the basis of recent dating of archaeological components from several sites along the Lower Salmon River. In another case, the temporal boundary of one of Butler's original phases are expanded to include new discoveries. The remainder of Butler's phases are unchanged, with additional supporting information added from the more recent investigations. Figures are provided to show artifacts associated with the different phases, and are intended to provide examples in addition to those reported by Butler (1962, 1969). Archaeological data from published (Davis and Sisson 1998) and unpublished sources (Davis and Schweger n.d.; Davis, unpublished data) are used to define and expand these phases.

Cooper's Ferry I Phase (11,500 - 11,000 (?) yr BP)

Cultural evidence defining this early phase was recovered from the lower portion of the Cooper's Ferry site (10IH73) and represents a limited occupation by peoples bearing a stemmed point technology (Davis and Schweger n.d.). Most notable is the discovery of four stemmed points, similar to the Lind Coulee type of eastern Washington (Daugherty 1956), within a pit cache that extended into the basal gravels of the site. Typologically, this phase is dominated by Lind Coulee projectile points (Figure 111), but includes a complete and a mid-section fragment of two Haskett points found by Butler (1969:Figure 6g and 6m). Other tools include bifaces and unifaces made on thick flakes, multidirectional flake cores and modified flakes used for expedient tasks. Lithic materials associated with this phase comes from sources found near the site today.

Cooper's Ferry II Phase (11,000 (?) - 8,400 yr BP)

Assemblages attributed to this phase were encountered at Cooper's Ferry in the middle portion of the site, stratigraphically above the geologic units bearing Cooper's Ferry I Phase components. Cooper's Ferry II Phase assemblages include stemmed and lanceolate points (Figure 112) comparable to Windust Phase styles from the Lower Snake River Canyon (Leonhardy and Rice 1970; D.G. Rice 1972) and Clearwater River areas (Ames et al. 1981; Sanders 1982; Sappington 1994). This phase also includes scrapers made on large flakes (see Figure 112:Cat. #73/642), bifaces, many modified flakes with edge wear and unlined hearth features associated with dense artifact compositions. Hunter-gatherers appear to be using the riparian environment of the Lower Salmon River more than in the previous period. This trend continues throughout the duration of the Cooper's Ferry II Phase as densely-occupied living surfaces, rising use of expedient and informal tools, and an increase in fish exploitation point to an intensification of site use and reduced resident mobility.

In the absence of radiocarbon dates directly associated with Cooper's Ferry II Phase assemblages in the LSRC, a relative age for the phase is provided through a comparison with other typologically-similar site components from the surrounding region. Points from this phase (especially Figure 112:Cat. #73/636; cf. Butler 1969:Figure 6) are identical to types grouped under the Windust Phase of the Lower Snake River

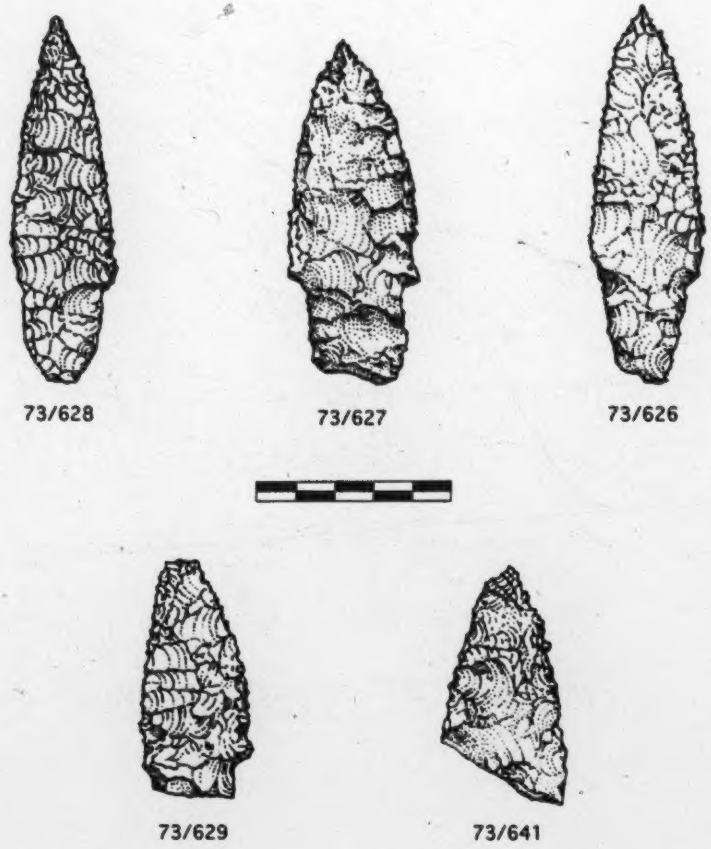
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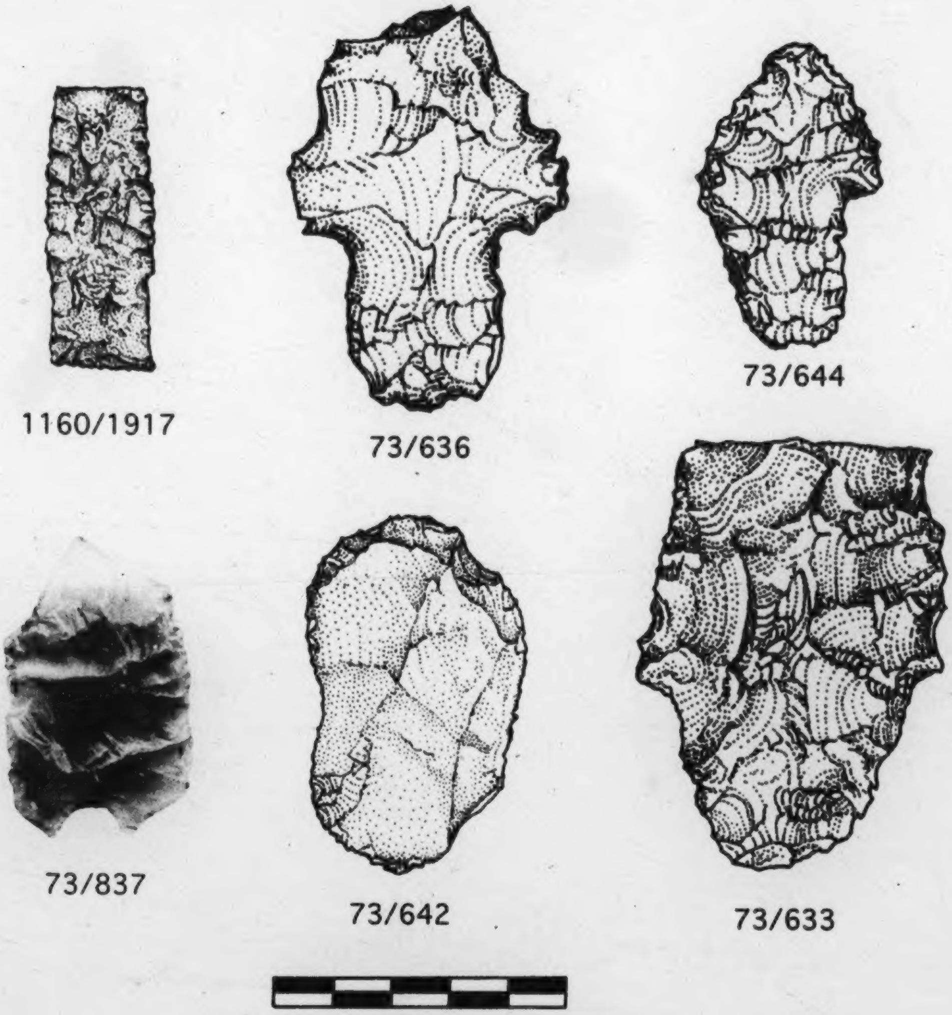
Figure 111. Projectile points and fragments of the Cooper's Ferry I Phase. Scale divisions are in centimeters. Catalog numbers are positioned beneath each point.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73/644
73/837
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73/633

Figure 112. Projectile points and fragments of the Cooper's Ferry II Phase. Scale divisions are in centimeters. Catalog numbers are positioned beneath each point.

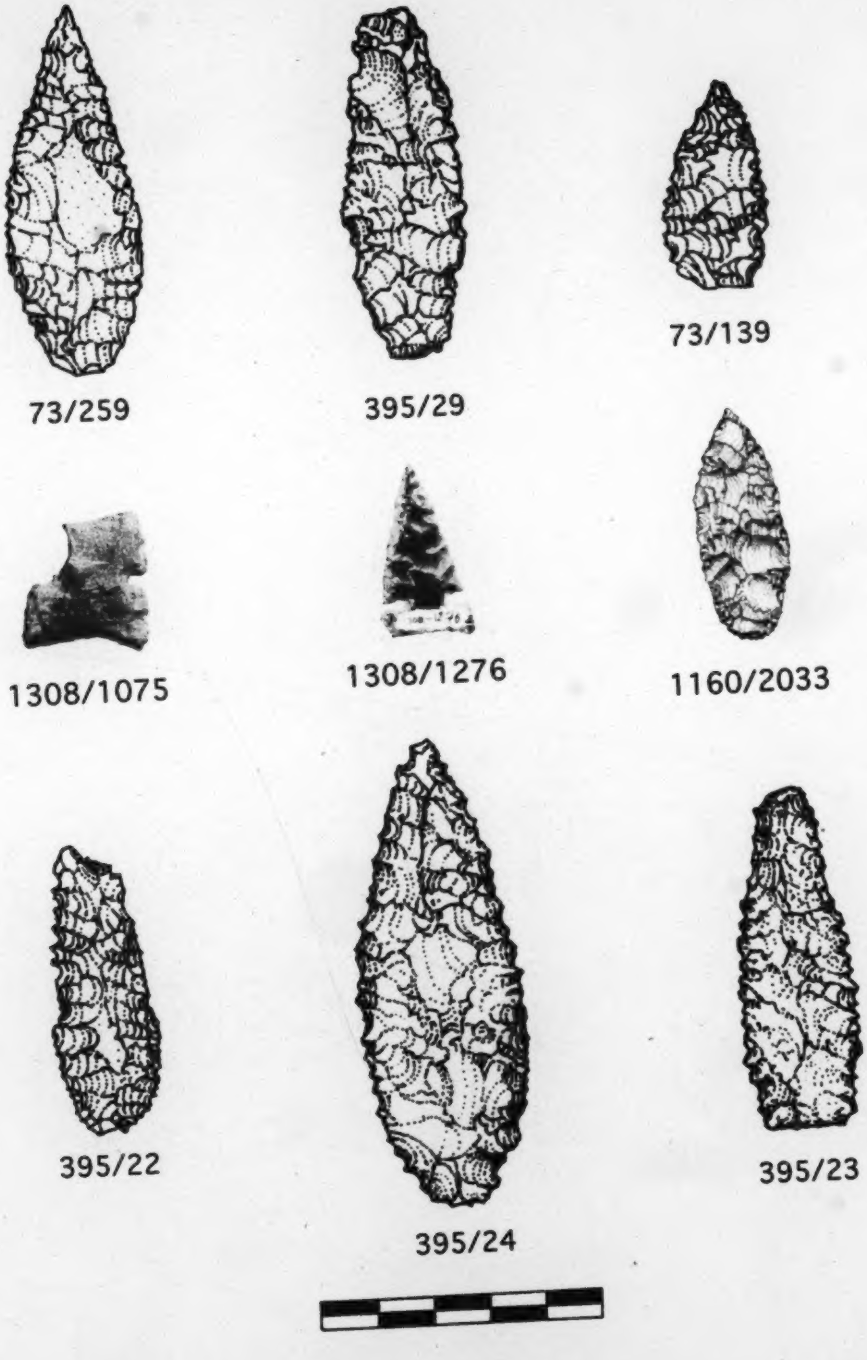
Canyon, which are dated between ca. 11,000 and 9,000 yr BP (Leonhardy and Rice 1970; D.G. Rice 1972). Square-based stemmed points were found at the Hatwai site near Lewiston, Idaho where they are dated between 9,160 ±230 and 10,820 ±140 yr BP (Ames et al. 1981; Sanders 1982). Radiocarbon dates between 9,730 ±60 and 10,320 ±90 yr BP bracket cultural occupation with stemmed Windust points at the Hetrick Site near Weiser in southern Idaho (Rudolph 1995). A stemmed point found in association with the Buhl Burial (Green et al. 1998), which is identical to that seen in the Hatwai I component of the Hatwai Site (Ames et al. 1981; Sanders 1982), was dated to 10,675 ±95 yr BP. Stemmed points encountered at the McCulley Creek site (10IH1160) along the LSRC were found below a radiocarbon date of 8,760 ±70 yr BP (Beta-142166) (Davis, unpublished data). These points bear close resemblance to Windust points found in Lower Snake River Canyon sites (H.S. Rice, 1965; D.G. Rice 1972:Figure 4c) and the Paulina Lake site at Newberry Crater in central Oregon--where they are dated between ca. 8,500 - 10,000 yr BP (Connoly 2000).

Craig Mountain Phase (8,400 - 3,500 yr BP)

Cultural evidence found during 1997 excavations provides a basis for placing the lower boundary of the Craig Mountain Phase, as defined by Butler (1968), to ca. 8,400 yr BP. Excavations at the American Bar and Cooper's Ferry sites revealed a record of intensifying settlement within and use of riparian environments, including the increased exploitation of river mussels and hunting of deer. Leaf-shaped points appear in both sites immediately before and by 8,400 yr BP, and dominate the typological assemblage during the Craig Mountain Phase (Figure 113). The record from Weis Rockshelter shows continuity in projectile point styles from 7,400 to 3,500 yr BP, suggesting a long technological tradition. Cold Springs Side-Notched points, found at Weis Rockshelter, were also recovered at Gill Gulch in middle Holocene-age deposits (Figure 113).

Grave Creek Phase (3,500 - 2,000 yr BP)

Cultural occupation intensifies on developing alluvial fans and on an ever-growing alluvial floodplain during this period. The increase in grinding and milling stone artifacts--possibly used for camas processing--may be related to ecological changes following increases in rainfall (Davis and Muehlenbachs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395/29
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1308/1075
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Figure 113. Projectile points and fragments of the Craig Mountain Phase. Scale divisions are in centimeters. Catalog numbers are positioned beneath each point.

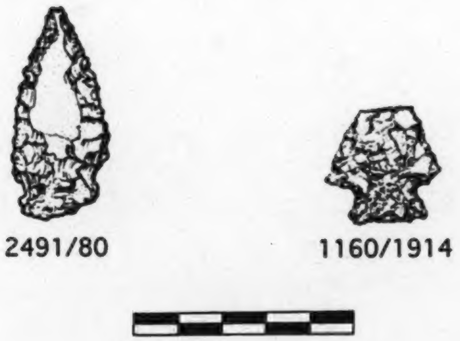


Figure 114. Projectile points and fragments of the Grave Creek Phase. Scale divisions are in centimeters. Catalog numbers are positioned beneath each point.

2001) and decreases in temperature and aridity (Davis et al. n.d.) seen after 4,000 yr BP. Cultural occupation of riverine sites like Nipehéme Village intensify, although appear to lack the presence of living structures and storage pits seen in sites throughout much of the Lower Columbia River basin during this time. Projectile points from this phase appear as notched varieties comparable to those recovered by Butler (Figure 114).

Rocky Canyon Phase (2,000 - 600 yr BP)

Cultural occupation intensifies further at most sites after 2,000 yr BP, marked by the presence of organic-rich sediments, dense accumulations of food and tool processing debris, and the first appearance of house pits. This phase post-dates a period of channel erosion of the Lower Salmon River, which resulted in the formation of the modern fluvial context (Davis n.d.). As a result of this geologic change, many Rocky Canyon Phase sites are located on the lowest terraces and active floodplain of the Salmon River. Tools indicative of salmon fishing also appear during this time, including net weights and bone tools possibly used in the construction and repair of nets. Production of ornamental items like mussel shell and mammal bone beads is also seen during this time. Representative projectile points are shown in Figure 115.

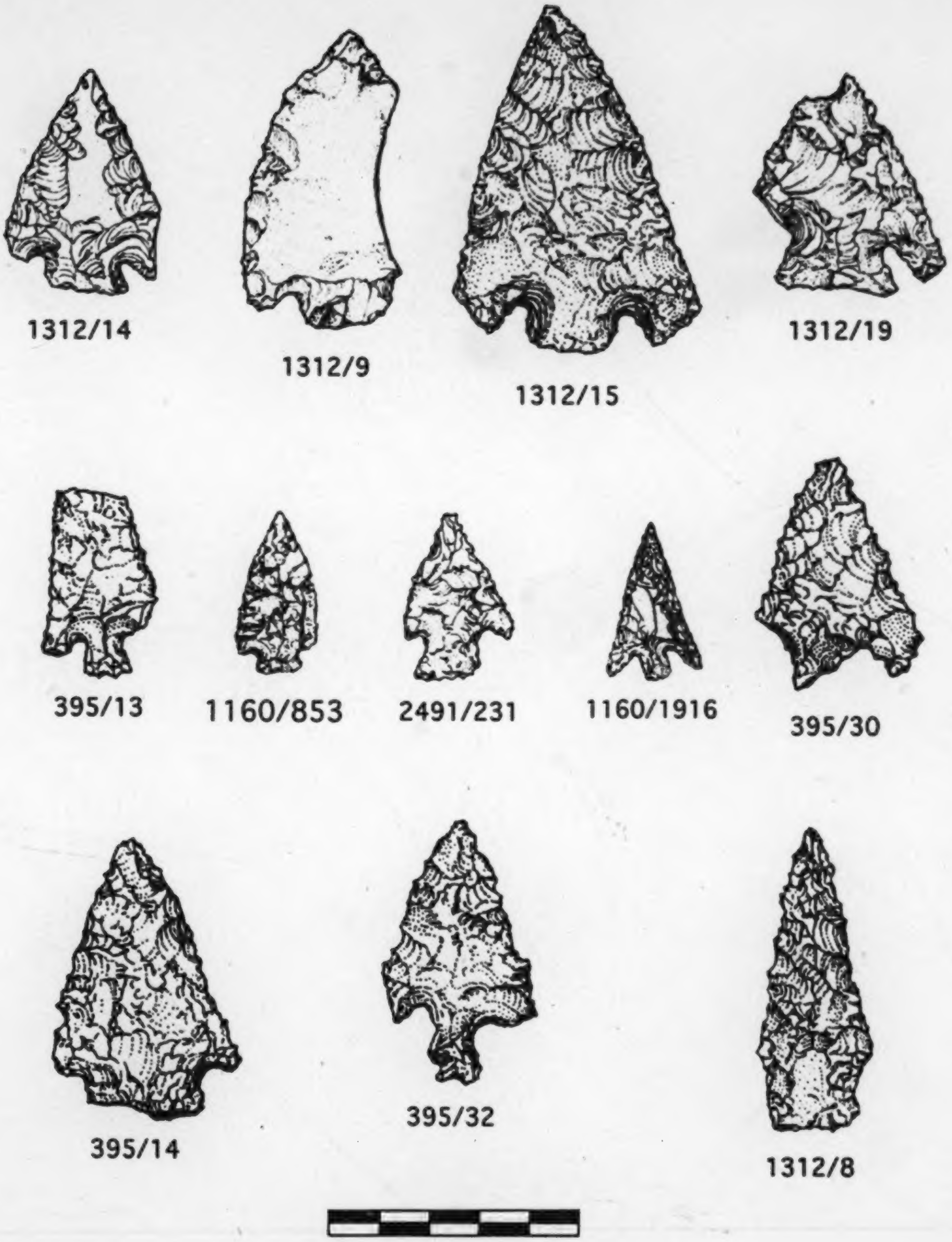
Camas Prairie Phase (600 - 150 yr BP?)

Evidence collected in recent excavations supports Butler's definition of the Camas Prairie Phase (Figure 116). Excavations at the Gill Gulch site recovered charcoal associated with a semi-circular pithouse feature, which dated between 300 ±70 and 460 ±70 yr BP. The presence of ethnohistoric artifacts at the Nipeheme Village site, including a glass bead, suggest a terminal Holocene temporal context in the absence of direct radiocarbon dates.

Discussion

Early Cultural Patterns

As in other areas of the Pacific Northwest, Butler's argument that a post-glacial migration of peoples bearing the Old Cordilleran Culture technology explained the early archaeological record of the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1312/9
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1312/19
395/13
1160/853
2491/231
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395/30
395/14
395/32
1312/8

Figure 115. Projectile points and fragments of the Rocky Canyon Phase. Scale divisions are in centimeters. Catalog numbers are positioned beneath each point.

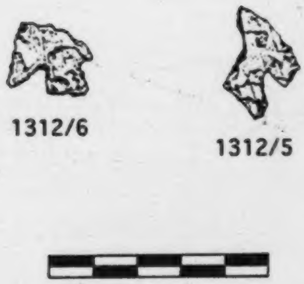

Figure 116. Projectile points and fragments of the Camas Prairie Phase. Scale divisions are in centimeters. Catalog numbers are positioned beneath each point.

Pacific Northwest is not supported by recent discoveries in the LSRC. As evidence showed stemmed point traditions were a temporal precursor to the development of leaf-shaped point styles (Leonhardy and Rice 1970), Butler's model was dealt a fatal blow. Despite this, his idea that the earliest peoples probably used non-fluted lanceolate projectile points during the late Pleistocene may still stand--particularly when the timing of the earliest occupation of Cooper's Ferry is considered--although for different reasons than he originally suggested.

Butler's ideas of a trans-Cordilleran route of entry and dispersal in the Pacific Northwest is not likely either, particularly since the oldest sites are found in the Southern Plateau area (Ames et al. 1998). On the other hand, his hypothesis that major river systems provided major routes of entry is still useful--particularly where a coastal migration route is considered (e.g., Fladmark 1979; Gruhn 1988, 1993). Explaining why sites dating older than 11,000 yr BP are not found in greater numbers in the Pacific Northwest is difficult. Bryan's (1980) argument that catastrophic floods from glacial lake Missoula probably destroyed or deeply buried early sites in large portions of the Lower Columbia River drainage should be considered as a possibility, however, it cannot also be invoked to explain the absence of early upland sites.

The dating of a stratigraphic sequence of stemmed points from Cooper's Ferry beginning at 11,410 yr BP provides solid evidence for the antiquity and evolution of an early non-fluted technological tradition in the Pacific Northwest that is at least contemporaneous with the Plains Clovis tradition, and thusfar predates western Clovis sites in the Pacific Northwest and the Great Basin. The stratigraphic sequence of projectile point types recovered at Cooper's Ferry reveals what is interpreted as a master sequence of technological evolution from one unfluted lanceolate point style to another. This record is inconsistent with models that expect the development of stemmed point types from earlier fluted forms (Willig and Aikens 1988; Carlson 1988) and instead supports the assertion by Ames et al. (1998:103) that, "There is little evidence of a cultural continuum from Clovis to later-dating cultural manifestations in (the Southern Plateau)..."; an idea suggested earlier by Bryan as well (1988). As a result, we should discourage the continued use of early "Big-Game Hunting" (Willey 1966:37) technoevolutionary models from the Plains and surrounding areas and instead employ evidence from the Pacific Northwest in building more suitable regional models of early prehistory.

Cultural Presence During the Middle to Late Holocene

Cultural components dating to the middle Holocene are elusive along the Lower Salmon River, thusfar. The reasons for this are likely related to middle Holocene erosional and deposition events corresponding to changes in Salmon River fluvial geomorphology (Davis n.d.). As a result, less is known of how hunter-gatherers exploited riparian zones during this time period than of the preceding period. Geologic work conducted in the canyon revealed a middle Holocene record of relative stable riparian vegetation in the face of rising temperatures and aridity (Davis et al. n.d.; Davis and Muehlenbachs 2001), which likely provided an attractive context for hunter-gatherer occupation.

Despite the difficulty of locating cultural occupations along the river, evidence from Weis Rockshelter clearly identifies a cultural presence throughout the middle Holocene period without significant changes in material culture. While the record from Weis Rockshelter proves that people maintained a continuous presence in the canyon, we are not entirely clear how they were using the local ecosystems, particularly the riparian zone, from this evidence.

Butler (1968:100) reported Cascade and Cold Springs Side-Notched points being present in Weis Rockshelter between ca. 7,400 to 3,500 yr BP, interpreting this as evidence that, "...for the duration of the Altithermal interval the Old Cordilleran Culture pattern continued unchanged in the Clearwater Plateau region." Ruebelmann (1978) criticized Butler's radiocarbon chronology and archaeological interpretation of Weis Rockshelter, citing the lack of consistency between his dating of artifact types with those seen to occur in the Lower Snake River Canyon as evidence of error. Although more data is needed to clarify the middle Holocene period of LSRC prehistory, our research did not produced any evidence that would contradict Butler's hypothesis of cultural stability, at least as reflected in point styles.

In his evaluation of late Holocene prehistory along the Lower Snake River, Reid (1991:23) levels criticism at Butler's late Holocene cultural chronology on several points; the sum of which, "suggest that the Weis Rockshelter cultural sequence has outlived its utility, and should be retired from the pool of chronologies applied to Hells Canyon and the Clearwater Plateau." This criticism should be addressed, as Butler's original cultural history model is partially employed in the revised cultural sequence presented here.

Through a comparison of radiocarbon date from cumulative sediments at Weis Rockshelter, which contained a 1.0 m section spanning ca. 2700 yr BP, and Bernard Creek Rockshelter, which contains a 1.5 m section separated by overlapping radiocarbon ages, Reid hopes to illustrate an error in Butler's use of a normalized chronology at Weis Rockshelter. This cricitism fails to take into account the contextual nature of formation processes at each site. Besides the fact that these depositional process typically operate at different time scales, to expect that rates of sediment deposition should be the same or comparable at several sites within the same stretch of canyon is often unreasonable.

Reid criticizes Butler's definition of phases because of the "disproportionate" artifact sample used (1991:22). Specifically, 82 projectile points are used to define the Graves Creek phase, while only 13 artifacts (four of which are points) define the Rocky Mountain phase. This criticism is misplaced, perhaps, since Butler's cultural-historical work was one of the earliest in the region. To put it bluntly, Butler had to start somewhere. This critique would be more effective during a time when more information was available from the surrounding area to evaluate Butler's model. Reid's attitude toward suitability in sample size for defining cultural phases is curious, particularly since he supports the use of the Clovis point type in the Snake River as representative of the earliest cultural phase (Reid and Gallison 1996:47--Figure 19), even though it is yet to be found in a stratified sequence showing its relation to stemmed points, or chronometrically dated in the Plateau region.

Reid's use of Gaarder's (1967) conclusions to attack the Weis Rockshelter chronology seems to muddy the waters more than clarify the issue. In his study of the Eagle Creek site, located on the Camas Prairie, near Grangeville, Gaarder mentions the existence of unpublished radiocarbon dates from the Double House site (obtained, it seems through personal communication with Butler (Gaarder 1967:48)), that provide terminal dates for the Rocky Canyon phase at 355 ±38 yr BP (WSU-124), and the Camas Prairie Phase at, "approximately A.D. 1805-1810." Since the stratigraphic context of these dates is unclear, having, to this author's knowledge, never been formally reported by Butler, it is difficult to fully evaluate the meaning of Gaarder's statements. Reid (1991:22) uses this information as evidence that Butler's cultural chronology, "did not survive the first attempt to apply it outside Weis Rockshelter, even within the Rocky Canyon study area." While it is easy to agree that more work is needed to better establish the temporal and stylistic basis for defining the latest Holocene cultural phases in the LSRC, it is difficult to accept that Gaarder's (1967) paper represents a death-blow to Butler's original model.

Salmon Fishing and the Winter Village Pattern

Excavations at sites in the LSRC reveal little or no direct evidence of salmon in the form of bones, scales, or other physical remains prior to 2,000 yr BP. There are many factors that may restrict salmon remains from entering and/or remaining in the archaeological record including modes and location of processing, dietary choices and culinary behaviors, and disposal practices, to only name sources of cultural bias. Although skeletal remains of non-anadromous fishes are occasionally found in sites--most typically with the use of fine screening (≤ 1/8" mesh)--they are encountered in low quantities (e.g., it would be unusual to recover even 25% of the total vertebral remains of an single fish), suggesting that the operation of post-depositional factors futher bias the visibility of fish remains in the archaeological record after they are caught by humans. Despite these taphonomic factors, faunal remains from anadromous fishes are difficult to find in LSRC sites. Since the remains of smaller non-anadromous species are encountered instead, recovery methods used in excavation are not suspected.

Artifacts that can be directly related to salmon fishing appear only after 2,000 yr BP. The construction of semi-subterranean pithouses first appear in the LSRC at the Double House site where their initial use is dated at 2,040 ±190 yr BP. A single pithouse encountered at the American Bar site produced a date of 1,370 ±40 yr BP; whereas the most intensive occupation of the Nipeheme Village site, with a material culture signal suggestive of a semi-sedentary settlement, is seen after ca. 1,780 ±50 yr BP. Recent excavations at the Gill Gulch site (10IH1308) recovered evidence of a pithouse floor and a charred post; charcoal associated with this house feature returned ages between 300 ±70 yr BP (Beta-147093) and 460 ±70 yr BP (Davis, unpublished data). Sappington et al. (1995) report a date of 920 ±40 yr BP (Tx-8236) from the floor of pithouse at Island Bar (10IH395). Compared to river canyons in the surrounding region (Leonhardy and Rice 1970; Ames et al. 1981; Sappington 1994; Ames et al. 1998), the appearance of pithouses and their implication of a "winter village" pattern of seasonal occupation occurs later than expected in the LSRC. Part of the reason for this situation may lie in the small number of pithouses investigated to date in the canyon. Natural factors might also come into play, however, including the effects of the character and change of the Salmon River channel on anadromous fish habitat throughout the Holocene (Davis n.d.). More work is required to evaluate the role of natural systems in subsistence patterns of prehistoric inhabitants of the canyon, however.

Conclusions

Two new phases and temporal changes to another are proposed for a revised LSRC culture history model. Establishing a late Pleistocene age on early cultural occupation at the Cooper's Ferry site represents a significant addition to Plateau prehistory. The implications of a clarified early cultural chronology are wide-ranging and provides evidence of an evolutionary progression among non-fluted technological types across the late Pleistocene-early Holocene boundary. Butler's hypothesis of middle Holocene cultural continuity in the canyon cannot be refuted by more recent research in the LSRC and may eventually be supported after further consideration of new records of human-environmental interaction. The development of the winter village pattern and a subsistence economy involving intensive salmon fishing probably did not occur in the LSRC until after 2,000 yr BP--much later than in surrounding river canyons and valleys. The reasons for this are suspected to be related to significant changes in Salmon River fluvial geomorphology and its effects on anadromous fish ecology. Although the revisions presented here are substantial on some levels, it is expected that future archaeological and geoarchaeological research will lead to even better models of LSRC prehistory.

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CHAPTER NINE

A PREDICTIVE MODEL OF ARCHAEOLOGICAL SITE LOCATION IN THE LOWER SALMON RIVER CANYON, IDAHO, BETWEEN HAMMER CREEK AND AMERICAN BAR

Introduction

The material record of human activity contained in archaeological sites is continually subjected to the effects of diagenetic processes. These processes of destruction and alteration come from many sources, ranging from the behaviors of the site's past occupants to the biotic and abiotic mechanisms that operate after site abandonment (Schiffer 1987). Geoarchaeology has traditionally accepted the task of studying site formation processes, bringing its earth science perspectives to bear on the physio-chemical processes that alter, obscure, and destroy sites at different temporal and spatial contexts (e.g., Binford 1980, 1982; Rossignol and Wandsnider 1992; Stafford 1995; Waters and Kuehn 1996). Accepting that geologic processes often change landscapes and their associated microenvironments through time, it is expected that the resources and places used by past peoples were situated differently than organized in the present landscape. Thus, the distribution of sites across the landscape and through time may vary in relation to the pace and character of paleoenvironmental and paleolandscape changes. Since a wide variety of geomorphic, geochemical, and biotic processes may operate in concert to produce different effects from region to region, the presentation of case studies dealing with site taphonomy is important. This paper will discuss processes of site formation and preservation in the dynamic river canyons of the southern Columbia River Plateau by presenting a geoarchaeological case study from the Lower Salmon River Canyon of Idaho. This case study will show how the context of late Pleistocene to Holocene fluvial systems, climate conditions, and surficial geology led to the operation of certain depositional and erosional regimes, which preserved and destroyed archaeological evidence, biasing the evidence of cultural occupation in the canyon. This study reinforces the need for geoarchaeological investigations as part of archaeological research in dynamic landscape contexts.

A Geoarchaeological Model of Site Location in the Lower Salmon River Canyon

The headwaters of the Salmon River begin in the Salmon and Bitterroot Mountains of central and eastern Idaho (Figure 117), which rise above elevations of 3048 masl (10,000' asl). Tributaries of the Salmon River include the Lemhi River, the Pahsimeroi River, the South, Middle, and East Forks of the Salmon River, and the Little Salmon River. These tributary streams flow north and west, through granitic

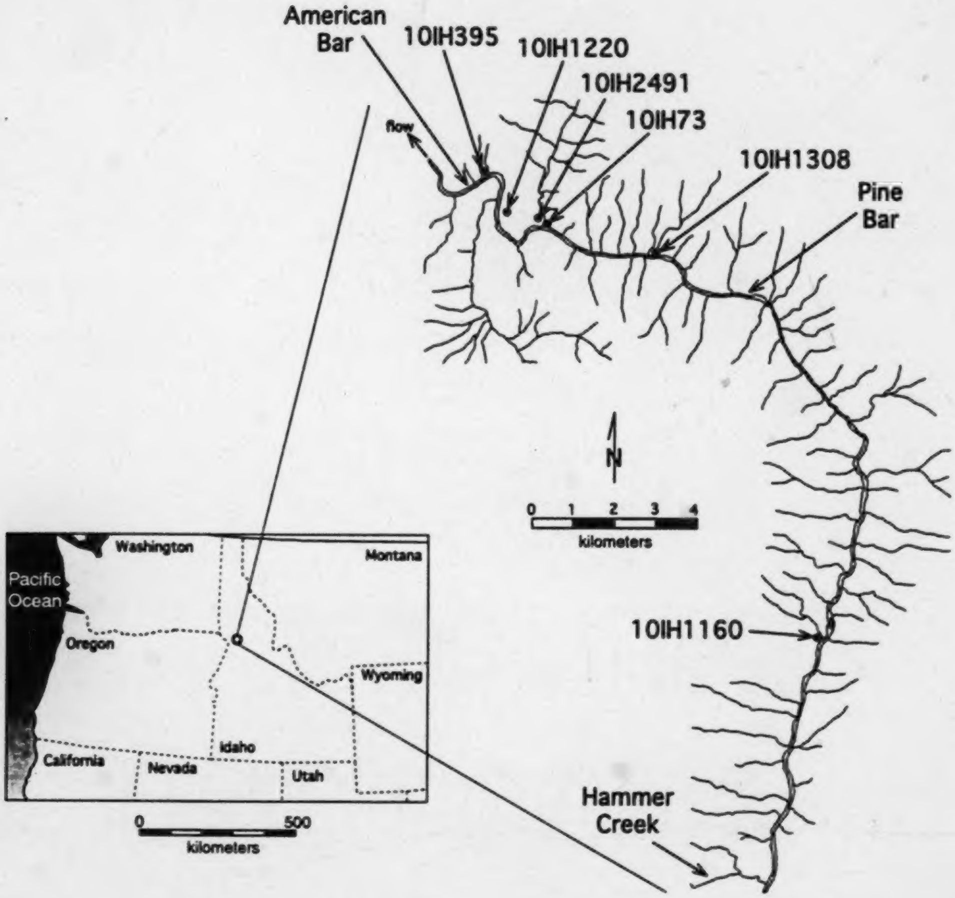
American Bar
10IH395
10IH1220
10IH2491
10IH73
10IH1308
Pine Bar
flow
N
0
1
2
3
4
kilometers
Washington
Montana
Pacific Ocean
Oregon
Wyoming
Idaho
California
Nevada
Utah
0
500
kilometers
10IH1160
Hammer Creek

Figure 117. Location of study area and sites mentioned in the Lower Salmon River Canyon, Idaho.

and metamorphic bedrock terrains of the Idaho Batholith. At Riggins, Idaho, the Salmon River turns north into a broader canyon. From this point, the Salmon River passes through sedimentary rock units of the Seven Devils Formation and along the boundary of the Batholith and the Columbia River Basalts. Downstream from White Bird, the Salmon River Canyon cuts through metavolcanic and volcanic bedrock units as it winds its way to the Snake River, which flows into the Columbia River and on to the Pacific Ocean.

The Lower Salmon River Canyon begins at the confluence of French Creek on the main stem of the Salmon River, about 20 miles upstream from Riggins, downstream to where it joins the Snake River. Above Riggins, the Salmon River is entrenched in narrow, steep-walled canyons. Downstream from Riggins many portions of the canyon are wider, with more gentle slope gradients. This is directly related to the resistance of bedrock units to the erosional action of the river. Between Riggins and White Bird, the Salmon River flows through mountainous terrains adjacent to the Salmon River Mountains to the east and the Seven Devils Mountains complex to the west, which forms the divide between the Snake River. Below White Bird, the Salmon River is flanked by large upland plateaus. The Camas Prairie lies to the north and east of the river, and the Joseph and Doumecq Plains are located to the south and west. Near the lower portion of the Salmon River, close to its confluence with the Snake, high relief terrains of the Craig Mountain area rise up to the north.

Unlike most of the major rivers of the West, the Salmon River is not impounded by hydroelectric dams, making it the longest free-flowing river in public ownership in the United States. Miners processed Salmon River surficial deposits with hydraulic placer mining methods in search of gold during the latter decades of the 19th Century and into the 20th Century. These activities left their mark on the Salmon River landscape. In some areas, where hydraulic mining was extensive, entire landforms may be missing. Because of the magnitude of these mining events, hydraulic placer mining assisted in the investigation of Salmon River Canyon geology. The erosional cuts left behind by placer miners provide many exposures from which geologic information was gathered.

Mean annual precipitation is varied in the basin. The bottom of the Lower Salmon River Canyon receives 16.8"(42.7 cm) of rainfall and 7.4" (18.8 cm) of snowfall, as measured at Riggins. Higher elevations receive greater amounts of precipitation. Warren, Idaho averages 67.3 cm (26.5") of rainfall and 418.8 cm (164.9") of snowfall annually, while an average of 57.1 cm (22.5") of rainfall and 85.9 cm (33.8") of snowfall is reported from Cottonwood. Mean maximum and minimum temperatures vary from 19.2° C (66.3° F) to 5.5° C (41.9° F) in lower elevations of the basin, and 10.9° C (51.4° F) to -6.2° C (21.0° F) in the higher elevations. The Lower Salmon River Canyon is inhabited by subalpine forests and semi-arid shrub grasslands in its more mesic upper elevations, and predominantly semi-arid shrub grasslands in the lower reaches, where it receives more warmth and less precipitation.

Annual discharge of the Salmon River is largely controlled by the melting of accumulated snowpack in the upper reaches of the basin. Of greater influence than rainfall, the annual melting of the snowpack controls annual rates and timing of alluvial discharge values. In his overview of the environmental setting of the Lower Salmon River, Sisson (1985) characterizes its modern alluvial behavior in the following manner: As measured at the White Bird gauging station, the mean annual discharge of the river is 10,690 cubic feet per second (cfs) (302.7 cubic meters per second (cms)). Maximum discharge was placed at ca. 130,000 cfs (ca. 3681.6 cms), while the lowest measured flow lies at 1,580 cfs (44.8 cms). Averaging 67,000 cfs (1897.4 cms), peak flow typically occurs between May and June as rising spring temperatures and rain-on-snow events melt the snowpack. By September, Salmon River discharge is at its lowest point. River flow remains subdued throughout the fall and winter months.

The predictive capability of the model to be proposed is based on a knowledge of where archaeological components of different ages are located in the landscape, as revealed in the results of excavations. Archaeological excavations in the LSRC are rather limited in scope, sampling only a minute percentage of existing landforms. To make up for this gap in the immediate knowledge of site location, attention is given to the available stratigraphic database, which may be used to make predictions about the distribution and condition of different deposits that are known to have associations with certain archaeological components. This study incorporates geomorphic and stratigraphic research conducted by Davis (n.d.2) in the study area.

Only those sites and geologic deposits below 549 m above sea level (masl) (1800' above sea level (asl)) along the Lower Salmon River between Hammer Creek and American Bar (see Figure 117) are considered. The focus is on the geology of the last 12,000 years Before Present (yr BP). Information from archaeological excavations conducted in the LSRC during the 1960s (Butler 1962, 1969) and in the 1990s (Davis and Schweger n.d.; Davis n.d.2; Davis unpublished data; D. Sisson, personal communication 1997) and recent geologic research (Davis n.d.1) provides a basis for coordinating archaeological-geological associations. If no information is available on buried archaeological components for a given landform, the temporal context of geologic deposits is considered. Where geological deposits are dated, predictions are made that a landform will contain archaeological components.

It is not difficult to accept that Plateau hunter-gatherers would be attracted to the biodiversity and resource composition offered by riparian zones and rivers. Because of this, we expect that site diversity and visibility to be the highest in deposits adjacent to the river. This is also controlled by the relief in a canyon setting, where the most suitable landforms for habitation are found in the bottom of the canyon, as flat-topped or gently sloping alluvial terraces, point bars, floodplains and fans. Because of the potentially high biological productivity of the alluvial floodplain, a greater proportion of sites are expected below Pine Bar, as compared with the area upriver of this point.

This model employs several assumptions regarding the distribution of archaeological components: (1) the highest density of archaeological sites will be found within 100 meters of riparian zones, which include the past position of the Salmon River, tributary streams, and springs; (2) site density will greatly decrease in frequency beyond the riparian zone; (3) the riparian zone should include evidence of cultural occupation ranging from limited encampments to more intensive seasonal settlement; (4) the most intensively-used sites should be at the intersection of tributary streams and the Salmon River, and greater site preservation will occur on landforms with fine-textured sediments and near-level surfaces; (5) the highest temporal resolution and preservation of site occupation will occur on landforms where geologic deposition is relatively constant, of sufficient quantity, and experiences limited post-depositional alteration; (6) certain non-residential sites will be found in locations that are proximal to the associated activity (e.g., kill and primary butchering sites) and will not be easily correlated to landform types.

The spatial and temporal distribution of archaeological sites in the Lower Salmon River Canyon is presented in two parts. First, late Quaternary surficial deposits were mapped and coded to show their potential for containing archaeological components of different ages (Map 1). The rationale behind the predictions made on this map are based on the geologic potential for a given landform to contain archaeological deposits of certain ages. The estimation of probability in this map is qualitative and no emphasis was placed on differentiating the kinds of sites found and where they would be located in the study area (e.g., the relative distribution of kill/butchering sites vs. camp sites). Surficial finds are predicted where deposition rates are low or on landforms that were created prior to the earliest evidence of human occupation. In cases where landforms were disturbed by erosion, predictions are made of the status of archaeological occupations, as either partially or entirely disturbed. Second, a presentation of stratigraphic cross sections, both perpendicular and longitudinal to river flow, show the predicted distribution of cultural occupations relative to the stratigraphic sequence of geologic units.

Stratigraphic Perspectives on Cultural Occupation

Table 21 combines the cultural sequence from the Lower Salmon River Canyon (Davis n.d.2) with modes of sediment deposition, soil formation, and erosional episodes observed in the geologic record of the study area (Davis n.d.1). Synchronic and diachronic perspectives of cultural occupation in the changing landscape are provided to illustrate the nature of site preservation, destruction, and distribution in the LSRC.

Synchronic Perspective

The prehistoric record of the Lower Salmon River Canyon study area is broken down into seven synchronic periods, or "time slices" of different temporal lengths. These divisions are arbitrarily defined and intended to emphasize important events in canyon prehistory and geology. Generalized stratigraphic cross sections are shown in Figures 118 and 119. These cross sections correspond to the seven synchronic periods, and are intended to represent the general stratigraphic sequence that is seen in the area between Rock Creek and American Bar, where most of the sites used in this study are located. While any one site may not contain the entire stratigraphic sequence, the cross sections are useful as a heuristic device in order to illustrate the nature of geologic change and relative position of archaeological components through time.

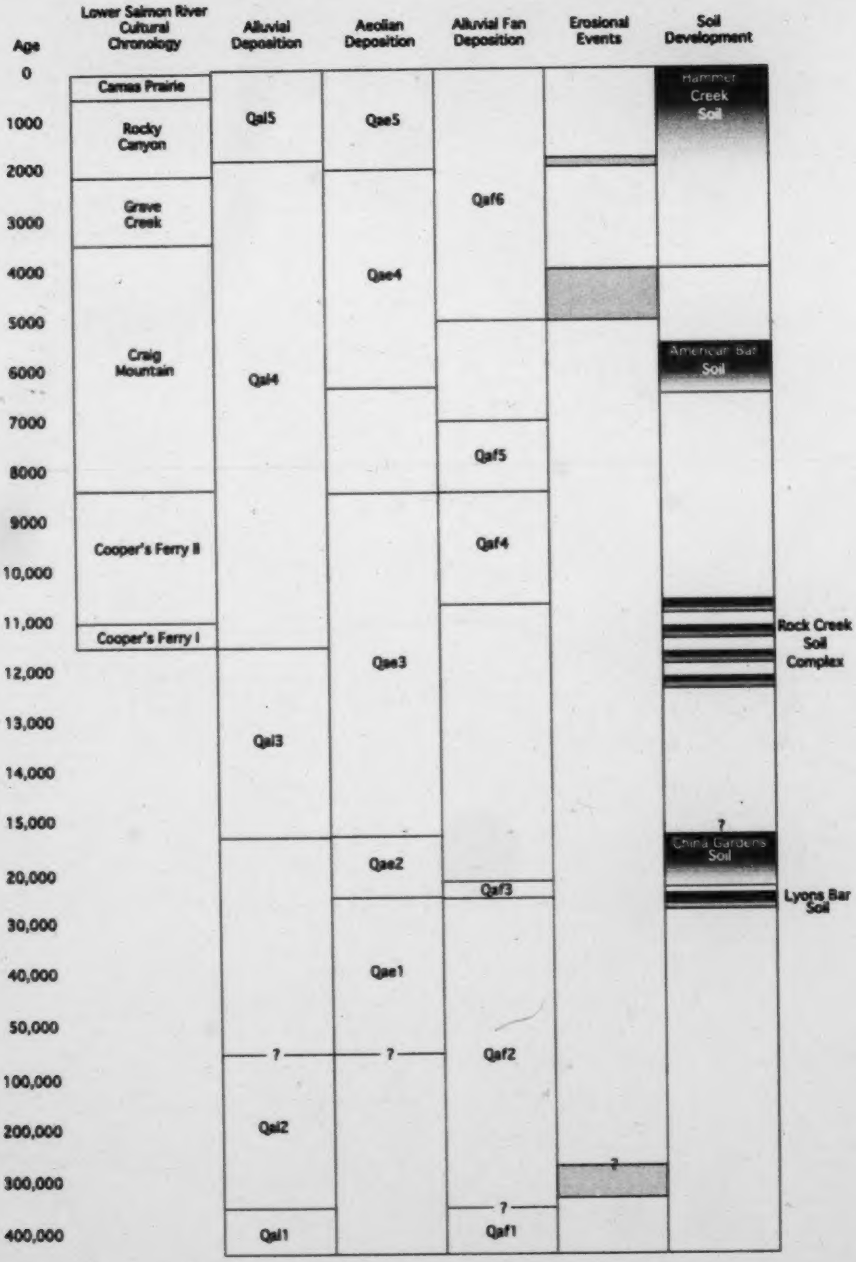
Age
Lower Salmon River Cultural Chronology
Alluvial Deposition
Aeolian Deposition
Alluvial Fan Deposition
Erosional Events
Soil Development
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
13,000
14,000
15,000
20,000
30,000
40,000
50,000
100,000
200,000
300,000
400,000
Camas Prairie
Rocky Canyon
Grave Creek
Craig Mountain
Cooper's Ferry II
Cooper's Ferry I
Qal5
Qal4
Qal3
Qal2
Qal1
Qae5
Qae4
Qae3
Qae2
Qae1
Qaf6
Qaf5
Qaf4
Qaf3
Qaf2
Qaf1
?
Hammer Creek Soil
American Bar Soil
Rock Creek Soil Complex
China Gardens Soil
Lyons Bar Soil

Table 21. Correlation of Late Pleistocene to Holocene Lower Salmon River Canyon cultural phases (after Davis n.d.2) with depositional facies, soil development, and erosional events seen in the study area.

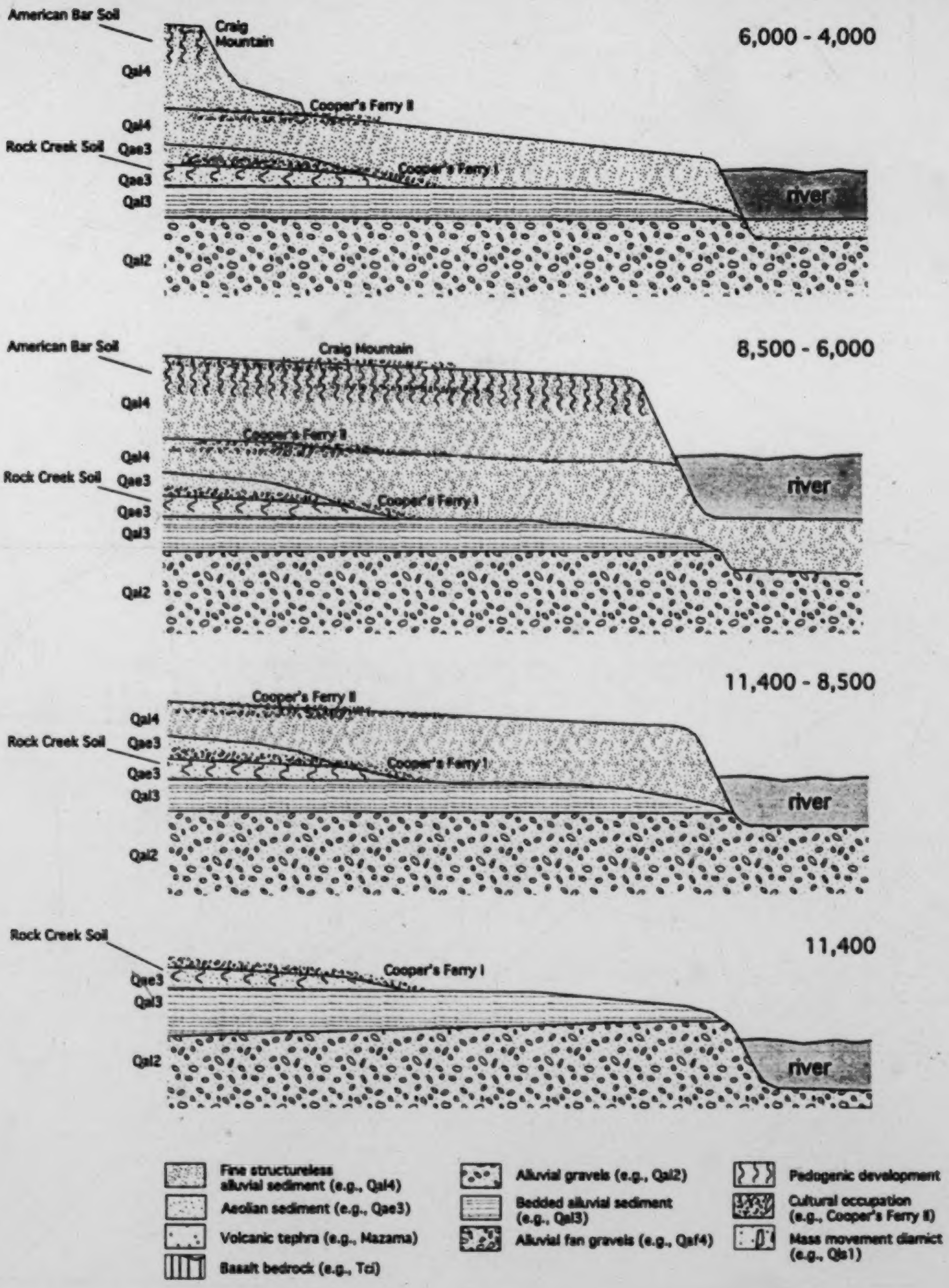
American Bar Soil
Craig Mountain
6,000 - 4,000
Qal4
Cooper's Ferry II
Qal4
Rock Creek Soil
Qae3
Cooper's Ferry I
Qae3
Qal3
river
Qal2
American Bar Soil
Craig Mountain
8,500 - 6,000
Qal4
Cooper's Ferry II
Qal4
Rock Creek Soil
Qae3
Cooper's Ferry I
Qae3
Qal3
river
Qal2
11,400 - 8,500
Cooper's Ferry II
Qal4
Rock Creek Soil
Qae3
Cooper's Ferry I
Qae3
Qal3
river
Qal2
Rock Creek Soil
11,400
Cooper's Ferry I
Qae3
Qal3
river
Qal2
Fine structureless alluvial sediment (e.g., Qal4)
Aeolian sediment (e.g., Qae3)
Volcanic tephra (e.g., Mazama)
Basalt bedrock (e.g., Tci)
Alluvial gravels (e.g., Qal2)
Bedded alluvial sediment (e.g., Qal3)
Alluvial fan gravels (e.g., Qaf4)
Pedogenic development
Cultural occupation (e.g., Cooper's Ferry II)
Mass movement diamict (e.g., Qls1)

Figure 118. Generalized geologic cross sections with associated archaeological components for the area between Rock Creek and American Bar during 6,000-4,000 yr BP, 8,500-6,000 yr BP, 11,400-8,500 yr BP, and 11,400 yr BP.

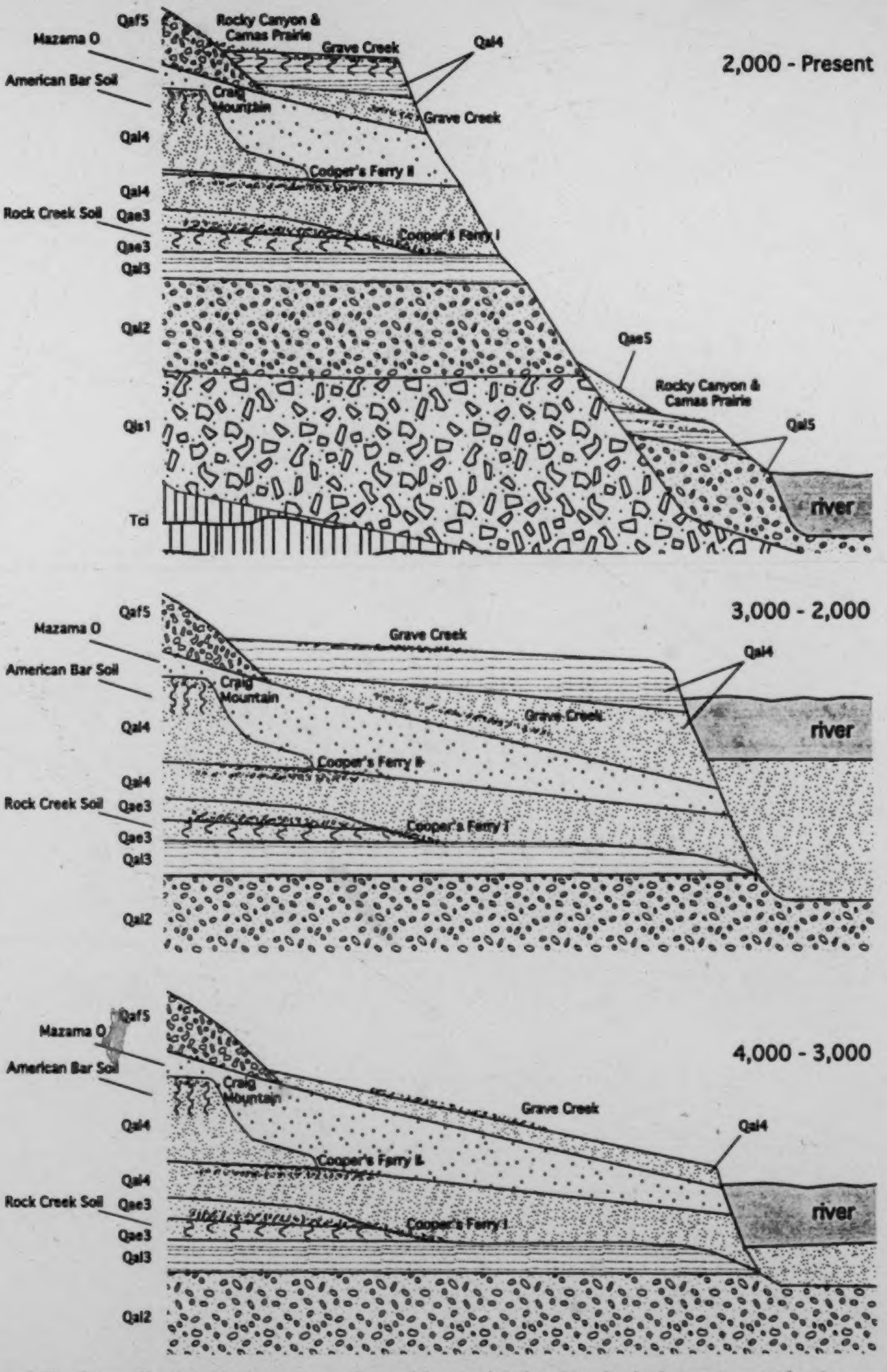
Qaf5
Rocky Canyon & Camas Prairie
Mazama O
Grave Creek
Qal4
2,000 - Present
American Bar Soil
Craig Mountain
Grave Creek
Qal4
Cooper's Ferry II
Qal4
Rock Creek Soil
Qae3
Cooper's Ferry I
Qae3
Qal3
Qal2
Qae5
Rocky Canyon & Camas Prairie
Qls1
Qal5
river
Tci
Qaf5
3,000 - 2,000
Mazama O
Grave Creek
Qal4
American Bar Soil
Craig Mountain
Qal4
Grave Creek
river
Cooper's Ferry II
Qal4
Rock Creek Soil
Qae3
Cooper's Ferry I
Qae3
Qal3
Qal2
Qaf5
Mazama O
4,000 - 3,000
American Bar Soil
Craig Mountain
Grave Creek
Qal4
Qal4
Cooper's Ferry II
Qal4
river
Rock Creek Soil
Qae3
Cooper's Ferry I
Qae3
Qal3
Qal2

Figure 119. Generalized geologic cross sections with associated archaeological components for the area between Rock Creek and American Bar during 1,000-0 yr BP, 3,000-2,000 yr BP, and 4,000-3,000 yr BP. Key for symbols and patterns provided in Figure 118.

11,400 yr BP

The earliest chronometrically-dated evidence of human occupation in the study area comes from the Cooper's Ferry site (Davis and Schweger n.d.). This early cultural occupation is seen on the surface of the Rock Creek Soil and in a pit feature that extends downward from the paleosol (Figure 118). An 11,410 ±130 yr BP AMS date comes from the surface of the paleosol and an 11,370 ±40 yr BP AMS date was returned from the pit feature. A cache of four stemmed projectile points of the Lind Coulee type (Daugherty 1956) were found in the pit as well. During the late Pleistocene this landform likely appeared as a portion of an alluvial floodplain, interpreted from fining-upwards sequence of alluvial sediments, which are capped by aeolian loess, and subjected to pedogenic alteration (Davis and Schweger n.d.). Fine alluvial sediments (Qal3) deposited along the river are the apparent the source of a loess (Qae3) that contains the Cooper's Ferry I occupation at the Cooper's Ferry site.

11,400 to 8,500 yr BP

By 8,500 yr BP, loess deposition (Qae3) capped the early cultural occupation at Cooper's Ferry, and was followed by a period of alluviation (Qal4) (Figure 118). A date of 11,310 ±80 yr BP (TO-7358) on bone collagen was returned from deer remains found on the surface of Late Pleistocene-Holocene Alluvium (Qal4) at SR-21, immediately across the river from the Cooper's Ferry site. Upriver, at SR-26-5, wood charcoal dating to 11,320 ±90 yr BP associated with the surface of a Rock Creek Soil Complex paleosol was buried by a brief return to aeolian deposition. Surficial stability and pedogenic development is seen again at SR-26-5 immediately before 10,740 ±220 yr BP. It appears that abrupt climate shifts from more arid to more mesic can be inferred between ca. 11,400 and 10,700 yr BP, producing alternating alluvial and aeolian sedimentation episodes.

Evidence for cultural occupation during period between 11,400 and 8,500 yr BP comes from the Cooper's Ferry site, the McCulley Creek site, and the Bug Slope site. Positioned stratigraphically above the cumulic Rock Creek soil at Cooper's Ferry, typologically-distinct projectile points attributed to the Cooper's Ferry II phase are seen in association with an aggrading floodplain (Qal4). Stemmed projectile points comparable to Cooper's Ferry II specimens are defined under Leonhardy and Rice's (1970) Windust Phase, which dated at 10,820 ±140 yr BP (Tx-3159) at the Hatwai site on the lower Clearwater River

(Sanders 1982:25), 10,675 ±95 yr BP (Beta-43055 and ETH-7729) from the Buhl Burial site (Green et al. 1998:440), between 9,730 ±60 yr BP (Beta-78722) and 10,320 ±90 yr BP (Beta-78228) at the Hetrick Site (Rudolph 1995), and from 7,400 ±100 yr BP (WSU-209) to 10,810 ±275 yr BP (WSU-386) at Marmes Rockshelter (Rice 1972:31; Fryxell and Keel 1969).

Between 10,800 and 8,500 yr BP, floodplain development along the Salmon River was relatively constant, reflected in the stratigraphy of the Bug Slope, Cooper's Ferry, and American Bar sites, and perhaps even at the base of the Rock Creek Bridge site. This is a noteworthy change from the environmental instability reflected in the shifting loessal and alluvial sedimentation regimes between ca. 11,400 and 10,700 yr BP. Cultural occupation intensifies on the aggrading floodplain (Qal4) immediately before 8,500 yr BP. At Cooper's Ferry, the recovery of thousands of artifacts per cubic meter attest to increased use of the Salmon River riparian zone during this period. Although less well dated, cultural materials are also recovered near the lower reaches of floodplain deposits at the Bug Slope site and also at the McCulley Creek site, pointing to a wider use of the developing alluvial landscape.

8,400 to 6,000 yr BP

Alluviation continued after 8,400 yr BP, reflected in the steady deposition of Qal4 sediments at the Bug Slope, American Bar, Rock Creek, Cooper's Ferry, McCulley Creek sites, as well as in many geologic sections (Figure 118). Alluvial deposition on the floodplain is reduced by 6,000 yr BP, allowing the formation of the American Bar Soil in some areas. Craig Mountain phase occupations can be found in alluvial sediments during this time period, pointing to a continued use of canyon riparian environments.

6,000 to 4,000 yr BP

The Salmon River eroded its banks between ca. 5,000 and 4,000 yr BP, destroying evidence of cultural occupation for the preceding period in many areas (Figure 118). Evidence from Weis Rockshelter (Butler 1968) shows a continued cultural presence between 8,400 and 6,000 yr BP, suggesting that geomorphic processes are the likely cause of differential presence of archaeological evidence, rather than cultural abandonment. Between 5,000 yr BP and 4,000 yr BP, the Gill Gulch site shows evidence of repeated hunter-gatherer occupation on a developing alluvial fan (D. Sisson, personal communication 1997;

Dickerson 1997). Alluvial aggradation occurs uninterrupted at the Rock Creek Bridge site after 6,780 ±50, suggesting that canyon erosion at this time is largely restricted to areas along the Lower Salmon River.

4,000 to 3,000 yr BP

Following the preceding erosional period, a return to alluvial deposition occurred again after 4,000 yr BP (Figure 119). Thick (≥1.0 m) deposits of Mazama O tephra are redeposited on the Lower Salmon River floodplain immediately before 3,000 yr BP. Alluvial deposition at the Bug Slope site caps this tephra deposit by 3,070 ±50 yr BP, while Qaf5 alluvial fan aggradation continues at the Gill Gulch, American Bar, and McCulley Creek sites (Dickerson 1997). Sedimentation begins at the Nipehéme Village site shortly before 3,930 ±60 yr BP. Cultural occupation is widespread in the study area during this period, with Grave Creek Phase components found in alluvial floodplain and alluvial fan deposits. Archaeological components dating to this synchronic period are found at the Bug Slope, Nipehéme Village, Rock Creek Bridge, Gill Gulch, and McCulley Creek sites.

3,000 to 2,000 yr BP

Between 3,000 to 2,000 yr BP, cultural occupation was seen at many sites. Alluvial sedimentation intensifies during this time, as archaeological materials are capped by Qal4 sand deposits (Figure 119). Floodplain aggradation reaches its maximum height during this period, seen at the Bug Slope and Rock Creek Bridge sites and as far upriver as SR-42. Because of the relative intensity of alluvial sedimentation, the vertical spacing of archaeological occupations in site stratigraphy is often pronounced.

2,000 to 0 yr BP

At ca. 2,000 yr BP, the Lower Salmon River channel incised through its floodplain, eroding adjacent archaeological-bearing landforms in the process (Figure 119). Renewed alluvial and aeolian sedimentation is seen along the post-2,000 yr BP position of the river, on point bars, and on the downstream side of fans. Cultural occupation along the newly-adjusted Salmon River appears to closely follow the formation of its new landforms. Examples of these settlements are seen at Lone Pine Bar, Pine Bar, and were probably widespread between McCulley Creek and Hammer Creek prior to the effects of historic placer mining.

Cultural evidence is widespread in geologic deposits dating to the last 2,000 yr BP, pointing to the continued use of riparian zones. In the lower portion of the study area, housepit features are often found in sites on the modern terrace. This was probably the case in the upper portion of the study area as well. Historic placer mining and agriculture practices altered the modern terrace in many places, however, biasing the archaeological record. Sites such as the Nipeheme Village, American Bar, and McCulley Creek include intensive cultural occupations positioned above the modern terrace. The difference in these sites lies in their proximity to tributary streams, which would provide a source of clean, fresh water (i.e., with less suspended sediment than the Salmon River).

The Double House site, located a short distance up Rocky Canyon, is positioned nearly 6 m (20') above the channel of Rock Creek. Radiocarbon dates from this site place its occupation between 365 yr BP and 280 yr BP (Butler 1968:99). Cultural occupation at the Nipeheme Village site shows cultural activity intensifying after ca. 1,800 yr BP. This intensity of occupation continues on into the ethnohistoric period, as evidenced by the presence of Euroamerican trade items. Charcoal from the floor of a housepit at the American Bar site places its use at 1,370 ±40 yr BP. The sporadic use of the Rock Creek Bridge site seen during much of the Holocene appears to cease by 1,960 ±40 yr BP.

During the 20th Century, intense erosion of alluvial landforms in the modern floodplain accompanied above-average seasonal flooding. Over the last 25 years, erosion of archaeological sites was seen at many points along the river, including Lone Pine Bar and Packers Creek, to name a few examples (D. Sisson, personal communication 1999).

Diachronic Perspective

Figure 120 shows the position of lithostratigraphic and pedostratigraphic units (after Davis n.d.1), archaeological components (after Davis n.d.2), past and present gradients of the Lower Salmon River, and the projected position of dip-slip faults in the canyon. This longitudinal projection reveals some interesting patterns of site distribution in the study area. Undisturbed archaeological components predating 2,000 yr BP are always well above the elevation of the modern Lower Salmon River channel. Although not shown in Figure 120, Camas Prairie components known from other sites not investigated in this study are often

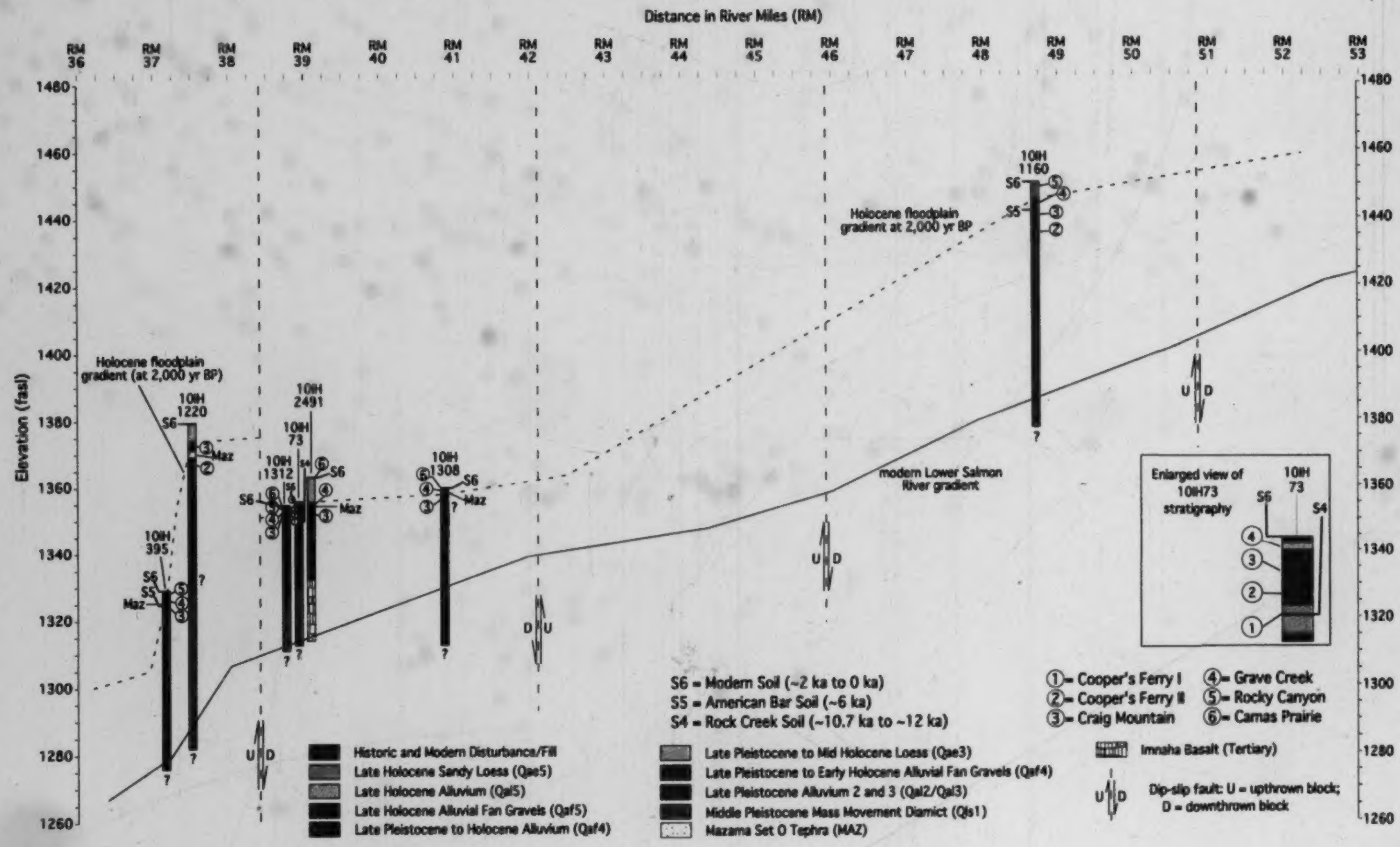

Figure 120. Longitudinal cross section of Lower Salmon River Canyon stratigraphy between Hammer Creek and American Bar, showing position of archaeological components relative to stratigraphic units and elevation (feet) above sea level (fasl).

distributed near the modern gradient of the river (David Sisson, personal communication 1999), providing evidence that hunter-gatherers quickly adjusted settlement patterns in response to the 2,000 yr BP alluvial channel incision event. Although the timing when the Salmon River cut though its canyon fill during the late Holocene corresponds with a large and abrupt increase in precipitation seen immediately after 2,000 yr BP (Davis and Muehlenbachs 2001), vertical displacement along a dip-slip fault line positioned at RM 38.2 probably contributed to the severity of channel incision--particularly if the two events occurred closely in time. Vertical displacement between contemporaneous floodplain deposits at 10IH1220 and 10IH2491 is nearly 6 m (20'); however, the rate at which this faulting occurred is unclear. If uplift of the channel had occurred below RM 38.2 prior to incision we would expect to see the deposition of alluvium upriver as the Salmon River sought to achieve a new channel gradient though aggradation. The fact that both 10IH1220 and 10IH2491 share the same alluvial stratigraphic sequence suggests that channel incision occurred simultaneously in the lower portion of the study area, likely predating any major uplift event. Therefore, the 2,000 yr BP alluvial downcutting was likely instigated by increasing alluvial discharge rates during a time of greater precipitation and enhanced by vertical displacement along the dip-slip fault line. The upriver propagation of channel incision occurred rather quickly in the study area, as earlier alluvial floodplain deposits were eroded and new lower-elevation alluvial landforms created (Davis n.d.1). As a result, major changes in alluvial behavior rapidly altered the character and structure of the LSRC riparian zone after 2,000 yr BP, providing new a new ecological context for hunter-gatherers.

Discussion

Geologic Controls on the Preservation and visibility of Lower Salmon River Canyon Sites

The distribution and frequency of radiocarbon dates across the last 12,000 yr BP provides some insights into the potential role of natural processes in the preservation and visibility of archaeological sites (Table 22, Figure 121). When combined with geologic evidence of erosional and depositional events, these data are even more useful. The selection of samples for radiocarbon dating imparts a bias on the coverage of radiocarbon dates, to some degree. Therefore, caution will be exercised in the interpretation of radiocarbon data, lest improper conclusions be advanced. Millennial and multi-century scale gaps in the radiocarbon chronology are seen between 2,000 and 3,000 yr BP, 5,000 and 6,000 yr BP and from ca. 9,200 to ca. 11,370 yr BP. This does not necessarily reflect the overall record of hunter-gatherer presence and absence in the study area. In several cases material culture was found in deposits that yield no datable samples. In other cases, however, stratigraphic unconformities and dating control clearly mark the presence of erosional events that possibly removed culture-bearing deposits of a given age. For example, erosion of the Lower Salmon River floodplain removed deposits dating between ca. 3,000 to 5,000 yr BP and radiocarbon dates for this time period come from sites in alluvial fans or rockshelters at positions above the floodplain.

Erosional Periods and Missing Archaeological Data

Erosion occurs constantly within a river canyon, operating at various scales of time, space, and energy. Identifying the timing and extent of erosional events in the Lower Salmon River Canyon is important to understanding the character of the archaeological and geological database. Two distinct erosional events occurred in the study area during the Holocene--between ca. 5,000 and 3,000 yr BP, and immediately after 2,000 yr BP. Evidence of this erosional activity in the canyon is seen at several points along the Salmon River. At the Bug Slope site, the scoured surface of floodplain sediments are covered by a thick deposit of Mazama O tephra and renewed floodplain sedimentation containing charcoal dated to 3,070 ±50 yr BP. Beginning at 3,930 ±60 yr BP, alluvial sedimentation covered a clast-supported deposit of boulder-sized gravels at the Nipehéme Village site. Although undated, an erosional unconformity is seen in the upper sands of the Cooper's Ferry site and may be related to the period of renewed sedimentation at the Nipehéme Village site after 4,000 yr BP. Excavations at the American Bar site revealed a truncated paleosol (American Bar Soil) that returned a conventional humate date of 6,070 ±60 yr BP. This eroded soil surface was buried by a thick deposit of Mazama O tephra, which was in turn capped by alluvial fan gravel deposition (Qaf5) immediately before 1,780 ±50 yr BP. Radiocarbon dates on charcoal from the Rock Creek Bridge and McCulley Creek sites point to a end of floodplain sedimentation sometime between 1,960 ±40 and 2,320 ±90 yr BP.

Site	Site Number	Uncalibrated Age (^{14}C yr BP)
Gill Gulch	10IH1308	300 ±70
Gill Gulch	10IH1308	320 ±50
Gill Gulch	10IH1308	460 ±70
Nipehéme Village	10IH1312	1,140 ±60
American Bar	10IH395	1,370 ±40
Nipehéme Village	10IH1312	1,680 ±60
McCulley Creek	10IH1160	1,690 ±70
Nipehéme Village	10IH1312	1,780 ±50
Rock Creek Bridge	10IH2491	1,960 ±40
Rock Creek Bridge	10IH2491	2,010 ±40
Rock Creek Bridge	10IH2491	2,050 ±40
McCulley Creek	10IH1160	2,320 ±90
Bug Slope	10IH1220	3,070 ±50
Gill Gulch	10IH1308	3,340 ±60
Nipehéme Village	10IH1312	3,610 ±60
Gill Gulch	10IH1308	3,690 ±50
Gill Gulch	10IH1308	3,840 ±50
Nipehéme Village	10IH1312	3,930 ±60
Weis Rockshelter	10IH66	4,650 ±70
Gill Gulch	10IH1308	4,780 ±100
Gill Gulch	10IH1308	4,940 ±60
American Bar	10IH395	6,070 ±60
McCulley Creek	10IH1160	6,250 ±70
Weis Rockshelter	10IH66	6,300 ±100
Rock Creek Bridge	10IH2491	6,780 ±50
Weis Rockshelter	10IH66	7,340 ±140
American Bar	10IH395	8,360 ±80
Cooper's Ferry	10IH73	8,430 ±70
McCulley Creek	10IH1160	8,760 ±70
Bug Slope	10IH1220	9,170 ±180
Cooper's Ferry	10IH73	11,370 ±40
Cooper's Ferry	10IH73	11,410 ±130

Table 22. Radiocarbon dates from cultural occupations in the Lower Salmon River Canyon study area.

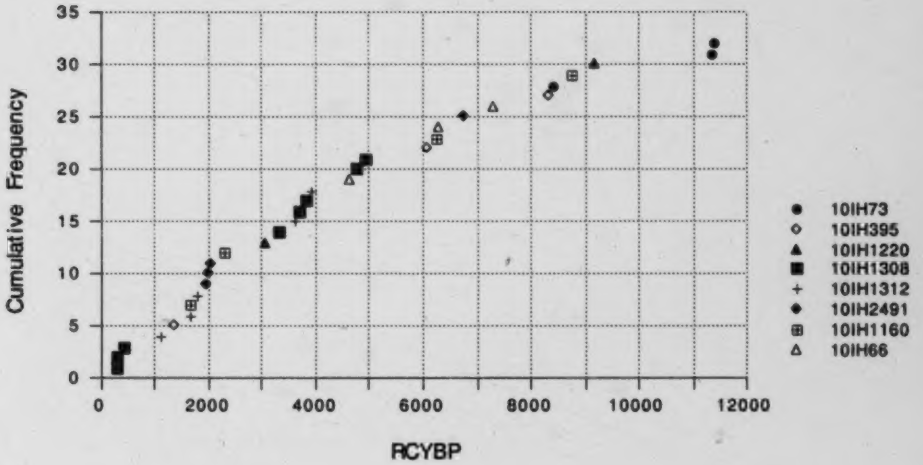

Figure 121. Frequency of radiocarbon dates on cultural occupations in the Lower Salmon River Canyon, Idaho. Dates are shown in uncalibrated radiocarbon years before present (RCYBP). Dates from Weis Rockshelter (10IH66) (Butler 1968) are also included here.

Floodplain erosion between ca. 5,000 and 3,000 yr BP removed middle Holocene geologic deposits and their associated archaeological components in portions of the canyon. The effects of this erosional period can be seen in the absence of radiocarbon dates between 5,000 and 6,000 yr BP. In some cases, erosion likely disturbed or removed early Holocene-age deposits, biasing our view of early prehistoric cultural occupation as well.

Alluvial downcutting caused the elevation of the Salmon River to fall between 45 feet (13.7 m) at SR-42 to a maximum of 95 feet (29 m) at the Bug Slope site. Primary geologic deposits located in the modern floodplain of the Lower Salmon River are expected to only contain sites dating to the last 2,000 yr BP. Artifacts attributed to cultural historical phases predating 2,000 yr BP may be found on the modern floodplain, but should be considered as redeposited materials, unless proven otherwise by careful geoarchaeological study.

Alluvial Fans

Alluvial fans offer unique preservation contexts in the canyon. In many cases, fine-textured culture-bearing sediments were found contained within alternating beds of poorly sorted, coarse clastic diamict. The writer observed high intensity, short duration rainfall events in the study area that cause widespread deposition of sediment on the surface of alluvial fans in the span of hours. Often, however, these fan sediments are dissected by their own streams soon after the depositional event. Where erosional processes were absent and deposition is relatively frequent, LSRC alluvial fans may hold well-preserved, high-resolution sequences of cultural occupation.

The Effects of Placer Mining

The legacy of historic placer mining in the LSRC effected a total loss of landform features and primary culture-bearing deposits in many areas. In some cases, where sluices were operated near prehistoric sites, artifactual material may be concentrated as a result of the mining process: as the surficial overburden is excavated, finer sediments are washed away to reveal placer gold and the remaining artifactual materials are deposited nearby. This phenomenon was observed at the McCulley Creek site where lumber fragments and an infilled trench feature were encountered, likely associated with a hand-operated sluice operation. Hundreds of artifacts, including projectile points, a bead, bone and shell debris, debitage, wood charcoal, and fire cracked rock, were found in the clearly-defined trench fill. Since disturbance associated with mining activities may produce unusual compositions of artifacts and sediment features that could be mistaken as representing primary prehistoric occupation, extreme caution should be exercised when conducting excavations near historic placer mining sites.

Some Keys for Identifying Relative Temporal Context in Stratigraphic Units

In cases where chronometric dating techniques cannot be used to establish the temporal context of archaeological occupations, several "rules of thumb" can be used to form an educated opinion about the relative age of geologic deposits in the Lower Salmon River Canyon.

Parent Material and Pedogenic Development

Upstream of McCulley Creek, late Pleistocene- to early Holocene-age aeolian and alluvial sediments are massive in structure, typically dominated by sand-sized clasts, include Munsell (Macbeth Division of Kollmorgen Instruments Corporation 1994) soil colors between light yellowish brown (10YR6/4) and yellowish brown (10YR5/4), lack well-developed soil structure, contain calcareous filaments and small globular nodules and moderate to strong effervescence (although decalcified sediments may also occur). Texturally, these early sediments fall into the textural boundaries of sandy loam and loamy sand.

From Cooper's Ferry to Bug Slope, late Pleistocene- and early Holocene-age alluvial sediments take on a different character. The Late Pleistocene-Holocene Alluvium (Qal4)--informally called the "brown alluvium"--is massive in structure (also lacking bedding structures such as ripples, trough features), possess sandy clay loam, loam, and silt loam textures, are seen in moist soil colors ranging from very dark grayish brown (10YR3/2), brown (10YR4/3), to grayish brown (10YR5/2), often contain small subrounded to subangular pebbles, and may include thin discontinuous carbonate filaments. In some sections, the "brown alluvium" spans nearly all of the Holocene and is not very useful for an age-specific stratigraphic marker. The carbonate-rich yellowish aeolian sediments seen upriver appear to be limited to the period before ca.

6,000 yr BP and can be used as a potential indicator of antiquity. Bone preservation is generally poorer in the yellowish calcareous aeolian and alluvial sediments than in the "brown alluvium".

Typically, paleosols are not well-developed along the Lower Salmon River. This is likely due to the relative instability of landform surfaces, as alluvial and aeolian sediments are constantly deposited on canyon surfaces. Three soil horizons are seen in association with archaeological components in the Lower Salmon River Canyon (see Davis n.d.1 for a more detailed discussion of soil units). These include: the Modern Soil, which likely developed over the last 2,000 yr BP or more and was the subject of study in Idaho state soil surveys (Barker 1982); the American Bar Soil, which is dated to ca. 6,000 yr BP; and the Rock Creek Soil, which is relatively weak in its development and dates between ca. 12,000 and 10,700 yr BP. Although pedogenic development potentially occurred at times other than these, when climatic conditions were favorable and landform surfaces were stable, the three soils mentioned above are identified in several places in the study area and may prove to be useful pedostratigraphic markers.

Geomorphic Context

The presence or absence of archaeological components in the study area is largely predicted on the temporal basis of landforms. Since the Salmon River aggraded for most of the last 12,000 yr BP, landform variability is rather low. The most significant changes in Holocene landscapes occurred after the river incised into its canyon fill following 2,000 yr BP. Thus, we should expect that intact archaeological deposits dating to the last two millennia should be found in the landforms closest to the modern riverbank.

Relative Depth

Since aeolian and alluvial deposition was relatively constant during the last 12,000 yr BP, with only a few short-lived periods of surficial stability (marked by soil development), archaeological components are typically found in well-stratified sequences. Late Pleistocene to early Holocene archaeological materials are found in the study area at depths of 1.5 to 4.0 meters below the modern surface. Surficial finds of early prehistoric cultural materials may potentially occur on landforms predating the late Pleistocene; however, aeolian sedimentation likely buried these sites in many areas. Because alluvial fans aggrade both vertically and horizontally, as sediments are transported and deposited as a single or multiple stream channel(s) migrate across the surface of the fan, the resultant stratigraphic record is typically vertically discontinuous. This produces a unique situation for the distribution of archaeological components in alluvial fan deposits, and the typical age/depth relationship seen in other LSRC landforms may not apply.

Volcanic Tephras

Throughout the Pacific Northwest, volcanic tephras are relatively common in archaeological sites and geologic sections. Since the timing and geochemical basis of individual eruptions is well known in the region, the presence of tephra layers is employed as a means of dating stratigraphic sequences and cultural occupations. The practice of using tephrochronologies as a dating method is not without its difficulties, however. Volcanic tephras should be considered relative age markers, unless the tephra layer can be proven to be a primary airfall deposit, or is accompanied by chronometric dates (e.g., radiocarbon). A lesson in the dangers of assuming tephra layers to be reliable, age-specific geologic markers is seen in the study of LSRC geology (Davis n.d.1). In several cases, volcanic tephras were identified to different well-known eruptions, but were found in association with much younger radiocarbon dates. For example, a truncated American Bar Soil horizon with humates dating to 6,070 ±70 was overlain by Mazama O tephra (dated to 6,700 yr BP (Bacon 1983)), which was in turn capped by alluvial fan deposits dating to the late Holocene. At the Bug Slope site, a charcoal date of 3,070 ±50 yr BP was recovered from alluvial sediments directly covering a thick deposit of Mazama O tephra suggesting its redeposition. Discontinuous lenses of Mazama O tephra were found in alluvial sediments bracketed by dates of 1,960 ±40 yr BP and 2,010 ±40 yr BP at the Rock Creek Bridge Site. At SR-26-5, which is located in a large alluvial fan at Lyons Bar, a layer of Glacier Peak G tephra (dated to 11,250 yr BP (Porter 1981)) overlies Rock Creek paleosols containing charcoal dated to 10,740 ±220 yr BP and 11,320 ±90 yr BP. Other Pleistocene-age tephras were redeposited thousands of years after their initial eruption.

In areas with high geographic relief, such as the Salmon River Canyon, we should expect that tephras would be subjected to redeposition some time after their initial airfall. For this reason, we must exercise caution when seeking to use them as temporal markers. Telltale signs of tephra redeposition in the Lower Salmon River Canyon easily observed in the field may include:

1. Overthickening of tephra deposits: since the canyon is located hundreds of miles away from Cascade Range volcanoes, we should expect that primary airfall layers would be measured in a few tens of centimeters thick, or less. For example, Matz (1991:41) projects the thickness of Mazama O airfall tephra for west-central Idaho to fall between 30 and 15 cm. Although extensive studies of other volcanic eruptions were not conducted in the same manner as Matz (1991), it is safe to assume that primary late Pleistocene- and Holocene-age airfall tephra layers distributed throughout west-central Idaho will be thinner than the primary Mazama O tephra. Exposures in alluvial fans and road cuts in many parts of the canyon reveal deposits of volcanic ash that are often meters thick and obviously redeposited.

2. Presence of internal bedding structures and the relative sorting of tephras are good indicators for the primacy of deposition. Airfall tephra should be extremely well sorted and lack gravels or non-volcanic sediment layers. Attention should be placed on the nature of the lower boundary of tephra units. Airfall tephras should also retain a sharp lower boundary that covers an undisturbed surface. Often, tephra layers occur on top of paleosols with irregular surfaces that lack A horizons, suggesting that tephra deposition followed a period of erosion. Such a sequence of erosion and deposition should be viewed as potential evidence for tephra reworking.

3. The stratigraphic position of tephra layers relative to other deposits or landforms can be a useful indicator of redeposition, particularly where paleosols or distinct geomorphic units are also seen. For example, the presence of Mazama tephra within the modern terrace cannot be accepted as representing a primary airfall deposit, as the landform post dates ca. 2,000 yr BP. Since alluvial fan deposits in the study area represent the accumulated clastic debris following tributary canyon erosion, tephras located in these landforms should always be viewed with caution.

Applicability of Model for Upriver and Downriver Areas

While the implications and predictive aspects derived from this information may be applicable to those areas upriver and downriver from the study area, this must be established independently. Upriver from Hammer Creek, the Lower Salmon River passes through some unique geologic deposits and tectonic zones associated with the Western Idaho Suture Zone (Maley 1987). East of Riggins, bedrock and structural context of the canyon changes again, as the Salmon River flows across the Idaho Batholith and its steep granitic slopes. Because of these geologic changes, the distribution and preservation of archaeological sites and their association with late Quaternary sediments may differ widely from that seen between Hammer Creek and American Bar.

Downstream of American Bar to its confluence with the Snake River, the Salmon River passes through sections of steep-walled canyons composed of metamorphosed volcanic rocks of the Wild Sheep Formation. An analogy for archaeological site distribution in this downstream section is seen between river miles 43 and 45 in the study area, where very limited sedimentation occurs and little preservation of sites is expected. Exceptions to this analogy are expected, of course, particularly in the Eagle Creek area and the section below Cottonwood Creek, where the Salmon flows through basaltic canyons once again.

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CHAPTER TEN

AN EVOLUTIONARY INTERPRETATION OF THE PALEOARCHAIC-ARCHAIC TRANSITION IN THE SOUTHERN COLUMBIA RIVER PLATEAU

Introduction

The archaeological record of late Pleistocene to early Holocene hunter-gatherers in the Southern Plateau region of the Pacific Northwest is traditionally characterized by subtle, yet important changes in technological, economic, and settlement patterns. Few reasons are cited to explain the timing and nature of these changes; rarer still is research that suggests the cultural processes that produced these changes. Recent archaeological and geoarchaeological work in the Lower Salmon River Canyon (LSRC) of west-central Idaho revealed a record of technological, settlement, and subsistence change within an evolving alluvial riparian environment. This work offers a means of evaluating both the changes in material culture and organizational behavior of early hunter-gatherers, and the environmental context in which these changes occurred. The nature of the human-environmental interaction in the LSRC is explored here in order to generate interpretations regarding the mechanisms behind early Holocene culture change recorded throughout the southern Plateau.

In order to accomplish this, several questions will be addressed: 1) Is the organization of hunter-gatherer mobility and technology systems from LSRC sites similar to that seen throughout the Southern Plateau during the early to middle Holocene?; 2) How were changes in early Holocene LSRC riparian ecosystems exploited by early hunter-gatherer groups?; 3) Can a link between changing riparian ecosystems and early cultural patterns be seen at other places in the Southern Plateau?; 4) if so, what are the implications of this human-environmental interaction?

Answering these questions will require several steps. First, a brief review of early Holocene Southern Plateau prehistory will set the stage for the main topic of this paper. Second, a summary of archaeological and geoarchaeological records of late Pleistocene to middle Holocene hunter-gatherers of the LSRC will be presented. Third, the early archaeological record of the canyon will be compared to regional patterns of prehistory through a consideration of available models dealing with technology, mobility and subsistence strategies. Fourth, the results of this comparison will be used to build hypotheses regarding the mechanisms involved in the change from Paleoarchaic to Archaic (*sensu* Beck and Jones 1997) cultural patterns in the Southern Plateau. This latter aspect will be accomplished by integrating geoarchaeological information presented in previous chapters in order to shed light on the context in which early hunter-gatherer cultural systems changed in the LSRC. Last, the results of this study will be evaluated against regional information on early culture change and riparian contexts during the early Holocene in order to make statements about the nature of the transition from Paleoarchaic to Archaic cultural traditions in the Southern Columbia Plateau.

Previous Research on Early Plateau Hunter-Gatherers

Early Holocene Cultural Markers

Daugherty (1962), and Leonhardy and Rice (1970) provided some of the first, and most long-standing early cultural sequences for the Southern Plateau. In their models, the earliest period of human occupation, termed the Pioneer Period, is defined archaeologically by the Windust and Cascade phases, which date between 11,000 to 4,500 yr BP. Windust components are widely distributed throughout the Plateau, represented at important sites like Windust Caves (H. Rice 1965) and Marmes Rockshelter (D. Rice 1972). The lower chronometric limit for Windust components is provided by a range of radiocarbon dates that cluster between 10,600 and 10,800 yr BP (Ames 1988; Ames et al. 1981; Cole 1966; D. Rice 1972; Sheppard et al. 1987), while an upper limit is seen at ca. 8,000 yr BP. Windust phase assemblages are primarily defined by the presence of a variety of stemmed and unstemmed lanceolate projectile point forms (Leonhardy and Rice 1970; D. Rice 1972), but also include bola stones, bone tools, polyhedral cores, and various flaked lithic tools. Windust peoples exploited a range of fauna from elk (*Cervus canadensis*), deer (*Odocoileus heminonus* and *O. virginianus*), pronghorn antelope (*Antilocarpa americana*), beaver (*Castor canadensis*), rabbits (*Lepus spp.*), to freshwater mussels (*Margaritifera falcata* and *Gonidea angulata*). Evidence for plant use is absent at this time, in either botanical or technological form.

Cascade phase assemblages date between about 8,000 to 4,500 yr BP, and are found to follow Windust components in the stratigraphy of several Plateau sites. The Cascade phase was divided into early (8,000 to 7,000 yr BP) and late (7,000 to 4,500 yr BP) subphases, on the basis of the later inclusion of side-notched projectile points (Leonhardy and Rice 1970). The namesake Cascade projectile point typically occurs in leaf-shaped lanceolate forms, and may include rounded or bi-pointed bases and serrated edges. Other artifacts found in Cascade assemblages include large lithic knives, steep-end unifaces (scrapers), and an increased presence of utilized flakes of various sizes. Cobble tools were employed for a wide range of activities as seen by bifacially-worked, pounded, and ground edges; whereas the presence of manos are thought to reflect food grinding (perhaps seeds), the specific activity in which "edge-ground cobbles" were used is unknown.

Faunal exploitation is similar to the Windust phase, with the addition of riverine resources such as *Margaritifera falcata* and *Gonidea angulata* mussel species, and fish, including large anadromous salmonids. Sprague et al. (1968) report one of the few occurrences of bison (*Bison* sp.) with non-typological lithic tools in early Cascade subphase-age deposits. Leonhardy and Rice (1970:9) note that, "Hunting technology seems the same as in the preceding phase. Indeed, the pattern of hunting deer and elk in the canyon thickets and antelope in the upland prairies continues through to the ethnographic period."

Bense's (1972) study of Cascade assemblages from 13 sites in the Lower Snake River Canyon of southeastern Washington provides a view on early Holocene settlement patterns. Bense suggests a pattern of cultural continuity in which people bearing a Cascade toolkit conducted similar activities during repeated occupations of small camps along the Lower Snake River between 8,000 and 7,000 yr BP. Increased reliance on river mussels, fish, deer, and possible plant processing are reflected during this period in the faunal remains and groundstone tools found in Marmes Rockshelter (45FR50), Granite Point (45WT41), and Ash Cave (45WW61), respectively.

Previous Interpretations of Early Plateau Culture

Schalk (1980) (see also, Schalk and Cleveland 1983) describes late Pleistocene to early Holocene hunter-gatherers mobility and logistical organization as having operated under a broad spectrum foraging strategy for the period between 11,500 to 4,200 yr BP. During this time, the author maintains that hunter-gatherers acted as foragers (*sensu* Binford 1980), employing generalized toolkits and frequent movement across the landscape to take advantage of a wide range of plant and animal resources. Schalk and Cleveland (1983) admit that the model may not account for all variabilty seen in Plateau sites through time, but is intended as a general framework to explain common trends seen in regional prehistory.

Schalk's broad spectrum foraging model was employed by Meatte (1990) to account for the pattern of early prehistory in the western Snake River Basin of southern Idaho, and adjacent areas of Oregon and Nevada. Drawing from a very small database of late Pleistocene- and early Holocene-age cultural components, Meatte admits that, "It is *assumed* that peoples responsible for the manufacture of the distinctive Clovis, Folsom, Windust, and Haskett type points pursued a highly mobile lifestyle while procuring an assortment of food resources. The hunting of big-game animals...could presumably have been complemented by a variety of small game animals, roots, tubers, and berries" (Meatte 1990:68, emphasis in original). Meatte recognizes several subsistence and technological changes at 8,000 yr BP in the western Snake River Basin, including the exploitation of a greater range of foods, the introduction of new, specialized tool types and the increased diversity of point styles. Interpretations of why these changes came about are not provided, however.

Ames (1988) presents a model of early forager mobility strategies for Southern Columbia Plateau hunter-gatherers on the basis of 13 assemblages from early to middle Holocene-age archaeological components in eastern Washington, north-central Idaho, and northeastern Oregon. Ames states that early Southern Plateau hunter-gatherers show a shift in logistical organization from collectors to foragers across the Paleoarchaic-Archaic transition period. Briefly stated explanations for the reasons behind this early culture change touch on issues of reproductive success and post-glacial environmental productivity (Ames 1988:335-336):

> At some point in the annual cycle, large temporary aggregations might form at very productive places--such as the major fisheries at the Dalles on the Columbia and the canyon of the Fraser River. The aggregations would be crucial to the reproductive success of a thinly dispersed population since they would allow individuals to find mates.

Under this adaptive strategy, Ames feels that the Cascade peoples employed a high degree of residence mobility, using a wide range of resources as they moved through large territories, with no significant reliance on riverine resources apart from those "very productive areas" where fishing was highly rewarding.

Interpreting Culture Change

Evolution and Culture

Evolution, as a concept connected with culture change, is a familiar theme in North American archaeology. Conceptually, evolution is used in different forms in anthropological and archaeological research, which provides an important means of distinguishing between schools of thought on culture change. The historical development of evolutionary thought in archaeology can be traced to the works of Herbert Spencer (1855) and Charles Darwin (1859).

Spencer and Sociocultural Progress

Spencer argued that social progress was innately tied to the natural order of human existence; that human society would naturally progress along a path of increasing complexity through time. These ideas were influential on archaeologists such as Tylor (1871), who presented a model of human development in which societies progressed through a series of stages from a basal form of tribal "savagery", ultimately arriving at a form of "civilization", marking the apex of social achievement. Although Spencerian ideas of cultural evolution do not follow the Darwinian concepts of biological evolution, Spencer was the first to present arguments for the operation of a larger force that might guide the development of sociocultural systems through time. Perhaps because Spencer emphasized change among sociocultural phenomena, instead of Darwin's biological interests, his progressive evolutionary view, however flawed, became an important part of European and North American archaeology during the 19th and 20th Centuries (e.g., Tylor 1871; Morgan 1877; Sahlins and Service 1960).

Cultural Evolution and the New Archaeology

Archaeologists continued to use a Spencerian mode of evolution into the 20th Century, although its appearance began to take on more sophisticated forms. The arrival of the New Archaeology was marked by an emphasis on the use of empirical scientific reasoning and techniques, and a professed interest in integrating evolutionary perspectives to better interpret cultural phenomena (e.g., Binford 1962, 1965, 1983; Watson et al. 1971). Leslie White's (1949, 1960) view that socieities progress, in regards to their relative organizational sophistication and ability to harness increasingly greater amounts of energy, is highly reminiscent of Spencerian views on social progress. White's ideas on social progression are explicitly reflected in the writings of his student, Lewis Binford (1972), and in other processualists such as Meggers (1960), who sought to relate culture in regards to its functional roots within different contexts. By establishing the link between certain behaviors and their functional roles in a cultural system, processualists believed that they could reveal the inner workings of culture process (Trigger 1989).

Under a processual perview, "changes in all aspects of cultural systems... were interpreted as adaptive responses to alternation in the natural environment or in adjacent and competing cultural systems" (Trigger 1989:296). With strong ties to ecological viewpoints, processualists typically de-emphasized an independent role for human cognition and decision-making as a source of culture change. Instead, views of cultural-environmental homeostasis and, "culture change as being initiated by non-cultural or external factors causing perturbation" (Trigger 1989:296) were favored. In its adherence to Whitean perspectives, the use of evolution in processualist explantions (sometimes referred to as a "cultural evolutionary" format) differs from approaches that incorporate Darwinan evolutionary concepts to explain culture change.

Darwinian Evolution

Charles Darwin's text *Origin of Species* (1859) provides the basic blueprint for the operation of biological evolution, particularly dealing with concepts of random variation, adaptation, and natural selection. Since its landmark publication, Darwin's concept of biological evolution continued to evolve through the works of 20th Century thinkers (e.g., Mayr 1959, 1972, 1977, 1982, 1988; Gould 1986). Darwin gives little discussion on the particular ways in which evolutionary concepts apply to the human species, providing room for differences in opinion. One side addressing this topic argues that humans have always been a part of the natural world and are therefore subject to the same evolutionary forces as other animals. Extreme adherence to this argument can be seen in the field of sociobiology, which treats cultural behavior merely as an extension of the human genome with behavioral patterns primarily dictated by one's genes, to less deterministic views embraced by Darwinian archaeological approaches. A relativistic perspective maintains that since humans are the sole possessors of culture among all animals, they are somehow endowed with the ability to be exempt or affected less by evolutionary forces than other biological organisms.

Darwinian Archaeologies

By the 1980s, the work of a handful of theorists (e.g., Dunnell 1980, 1989; Boyd and Richerson 1985; Leonard and Jones 1987; Rindos 1984; 1985, 1986, 1989; Teltser 1988; Mithen 1989) made important progress toward bridging Darwinian evolutionary theory and archaeology. Dunnell (1980) is a prominent voice at this time and provides some important bases for the formation of a Darwinian archaeological approach. A correct evolutionary approach to archaeology, Dunnell argues, should reject Spencerian views that consider social progress equated with evolution, and their Whitean manifestation in processual archaeology, since they lack the appropriate scientific and theoretical foundation to address culture change in an evolutionary framework. Instead, archaeology should incorporate Darwinian evolutionary concepts of variation, selection, and adaptation. Importantly, Dunnell also rejects sociobiology's emphasis on genetic transmission as the source of human behavior reflected in the archaeological record. Archaeologists wishing to avoid the genetic-deterministic standpoint of sociobiology realized that biological evolution could not be applied in its traditional format to explain human cultural phenomena (cf. Dunnell 1982). Various theorists attempting to articulate evolutionary theory in an archaeological framework at the close of the 20th Century contributed to the range in conceptual styles among "Darwinian archaeologies" (e.g., O'Brien and Holland 1990, 1992, 1995; Feathers 1990; Bettinger 1991; Dunnell and Feathers 1991; Dunnell 1995; Jones et al. 1995, Bettinger et al. 1996; Maschner 1996).

Differences among Darwinian archaeological approaches deal mainly with the manner in which the evolutionary concepts of variation, selection, and replication are to be applied to culture. At one end of this theoretical spectrum lie the deterministic views of evolutionay ecology, which consider culture to be environmentally determined through the processes of adaptation and natural selection. Evolutionary ecologists (sometimes termed *sociobiologists*), "stress the connection between cultural and ecological change and seek to correlate the two chronologically and specifically in order to link them in terms of cause and effect" (Dark 1995:177). Most examples of Darwinian archaeology, including that which is advocated in this study, argue for the inclusion of human cognition, the ability of humans to make choices, and the replication/transmission of behaviors as important (in lesser or greater degrees) to developing a productive evolutionary basis for archaeological theory.

A crucial distinction is drawn between evolutionary ecology and Darwinian archaeological theory, primarily on the basis of the latter's inclusion of a separate mechanism for the transmission of cultural behaviors (Bettinger 1991). Cultural transmission models used within a Darwinian evolutionary framework maintain that the transfer of cultural behaviors must be treated differently than its genetic counterpart. The transfer of genetic and cultural information is therefore considered to occur in asymmetric patterns. This can be seen in the fact that genetic information is passed along from only two persons at a time--one's biological mother and father; while cultural information may be transmitted to an individual from his family, social group, or society. From this standpoint, a Darwinian approach with an inclusive model of cultural transmission assumes, "...that culture is an extrasomatic means of transmitting programs of behavior and that because it is extrasomatic may not lead to behaviors that conform to the expectations arising from models in which reproduction is genetic" (Bettinger 1991:223). It is this concern with making the distinction that cultural behavior is not somatically-based (i.e., that an individual's behavior is provided, and literally determined, by his or her genes) that allows for the treatment of cultural behavior in a more productive arena. Because of their inclusion of Darwinian concepts of selection and adaptation, evolutionary archaeology is typically materialist, in that, "Darwinian arguments often stress that...cultural traits are often explained in terms of the way they help humans adapt to a particular ecological setting" (Johnson 1999:138). It should be noted, however, that the term *ecological setting* should not necessarily be limited to those purely abiotic or non-human biotic factors; in terms of human ecology (*sensu* Butzer 1982), social systems and their interactions can be of equal importance in an evolutionary perspective.

Definitions

Terms originally associated with Darwin's theory of evolution are commonplace in the archaeological literature, although not always used inn accordance with Darwinian thought. In order to avoid confusion as to the meaning of specific terms related to Darwinian evolution as they are applied to human culture some definitions should be provided. Darwinian evolution, as considered in both biological and selectionist terms, is defined as, "a particular framework for explaining change as differential persistence of variability" (Dunnell 1980:38). In the archaeological arena variability abounds, seen in the thickness of pottery vessel walls, the width and length of projectile points, or the shape and size of fins on 20th Century American automobiles. Evolutionary archaeology emphasizes the measurement and interpretation of change as a way to account for variability, which is the target of selective pressures: "Variability is the potential for variation to be produced. Selection operates upon actual *variants* that are produced" (O'Brien and Holland 1990:41). The production of variability, through the evolutionary process of natural selection, is undirected. This is in contrast with processual applications of evolution, which emphasized adaptation in terms of progressive development. A correct Darwinian perspective would not expect, indeed cannot predict, the outcome of the selective process. The outcome of selection, or simply that which "evolves" follows, "...a replacement-based process that produces new kinds; it does not gradually transform one thing into another" (O'Brien and Holland 1995:186; Dunnell 1980). Adaptation, then, is considered the, "morphological, physiological, and behavioral equipment of a species or a member of a species that permits it to compete successfully with other members of its own species or with individuals of other species and that permits it to tolerate the extant physical environment" (Mayr 1988:135), but should also account for the social environment as well. Mithen (1989:488) provides an expanded definition of adaptation that conforms to a Darwinian archaeological perspective:

> Adaptation is about staying alive and reproducing in competition with other individuals. It is not about achieving some optimal state of

> behavior. Individuals should be seen as attempting to improve their current performance in relation to others, not seeking the very best (Dawkins 1982:46). They may be attempting to improve their foraging efficiency, access to mates, degree of stylistic conformity in pot decoration, or any other means by which they engage in the process of adaptation to their social and physical environment.

It is perhaps easier to talk about studying adaptations than it is to produce data that address adaptive behavior among prehistoric peoples. On this account, O'Brien and Holland (1995:192) stress the importance of being concerned with the problems and not the solutions in evolutionary research, warning that, "...it must be kept squarely in mind that the link between determining certain features to be adaptations and deciding what the features are adaptations *for* rests on inference" (emphasis in original). In this view, Acheulian handaxes and shell-tempered ceramics would be considered examples of solutions to specific problems in the past. By focusing on what the problems were that could be solved by the adoption of a different strategy, say, the invention of a tool, or by establishing trading alliances, archaeologists are better positioned to address past behaviors from an evolutionary perspective. Another example might be that while the adoption of blade technology at the expense of biface production can be explained as a need for the increase in cutting edge per unit of lithic material, it fails to identify why the need for more cutting edge existed in the first place--that is, what problem was being solved by the switch to blades over bifaces?

Cultural Transmission

Dunnell (1980) acknowledges that, while the fact that cultural behaviors should be transmitable, just as genetic information is transmitable, the mode in which this transmission occurs is unclear, and represents a serious obstacle to the operationalization of evolutionary theory in archaeology. Boyd and Richerson (1985) suggest several mechanisms through which cultural behaviors may be transmitted, which provide an alternative to adopting a genetic analogy of transmission. These methods of transmission include *guided variation, frequency-dependent adoption* and *indirect bias*. Guided variation (Boyd and Richerson 1985:95) occurs when an individual considers a range of possible examples of a particular behavior (e.g., making and employing a style of projectile point), chooses to imitate the mean of the possibilities, and fine-tunes the behavior through trial and error. Frequency-dependent adoption (Boyd and Richerson 1985:208-209) involves a process in which an individual adopts, without modification, those cultural behaviors that are most commonly observed. In the operation of indirect bias, individuals choose among a ranked set of behavioral aspects, as ordered by social determination. Because the set includes other behavioral aspects that are grouped along with the desired or imitated behavior, the individual ends up adopting other cultural behaviors included in the set (e.g., semi-subterreanean pit house structure style is adopted as part of the set of behaviors associated with intensive salmon harvesting and storage). These last two culture transmission models are driven by social factors and are jointly referred to as "social transmission."

Developing Evolutionary Explanations for the Paleoarchaic-Archaic Transition

How then can we address the problem of the Paleoarchaic-Archaic transition in the LSRC in evolutionary terms? First, we must establish the data in a framework that is consistent with Darwinian evolution; namely, the nature of the variability in question must be empirically defined in a temporal format. This task was accomplished earlier by quantifying the diachronic dataset of site assemblage and subsistence data from the LSRC. Next, we must ask how the, "differential representation of transmitted variability in subsequent states" (Dunnell 1980:37) is reflected in our archaeological dataset. The statistical treatment of assemblage data may provide an answer here, in terms of its relationship to patterns of foraging behaviors during the late Pleistocene to early Holocene period. Finally, we must explain the observed variation in terms of its evolutionary fitness (O'Brien and Holland 1995). On this last point, Bettinger (1991:219) reminds us that, "Because in Darwinian theory evolutionary outcomes (consequences) are purely opportunistic, ungoverned by any grand design, the locus and action of reproduction and selection must be specified exactly to produce any expectation about consequence at all." Selection does not occur in a time or place removed from any contextual basis. Indeed, selective forces are derived from the natural or social environment. Selective pressures operate against individuals bearing these behaviors "*at a particular time and in a particular place*" (O'Brien and Holland 1995:181, emphasis in original). Because human behaviors are selected against, rather than selected for, we are able to view the archaeological record as a history of behavioral successes outcompeting less suitable strategies for survival. Explaining the observed variation of the Paleoarchaic-Archaic transition within its context, and in terms of evolutionary fitness will be provided in sections to follow, forming the basis for explanations of early culture change seen in the LSRC.

Geologic Context of Early Archaeological Components

Late Pleistocene to early Holocene archaeological components were recovered from five sites in the LSRC of west-central Idaho (Figure 122). These components date between 11,410 and ca. 6,000 yr BP (Table 23). Of these, only three sites produced cultural assemblages suitable for analysis and comparison with other sites in the region. Artifact assemblages, activity features and subsistence evidence from the Cooper's Ferry site, the American Bar site and the McCulley Creek site will be used in this study. In order to better appreciate the context of the cultural datasets, a review of site stratigraphy is in order.

Cooper's Ferry (10IH73)

The archaeological and geoarchaeological record of the Cooper's Ferry site is extensively treated in Davis and Schweger (n.d.) and will only be summarized here.

Geomorphic Setting

The Cooper's Ferry site is contained in a small terrace located on the upriver side of Rock Creek about 10 m (33') above the Salmon River. In the area of the Cooper's Ferry site, the Lower Salmon River is deeply entrenched into thick units of the Columbia River Basalt Formation (Maley 1987). The canyon is relatively broad in this area, with gradual rising side slopes. The upland plateau of the Camas Prairie and the Joseph and Doumecq Plains acts as divides between the Clearwater and Snake River Canyons, to the north and south, respectively.

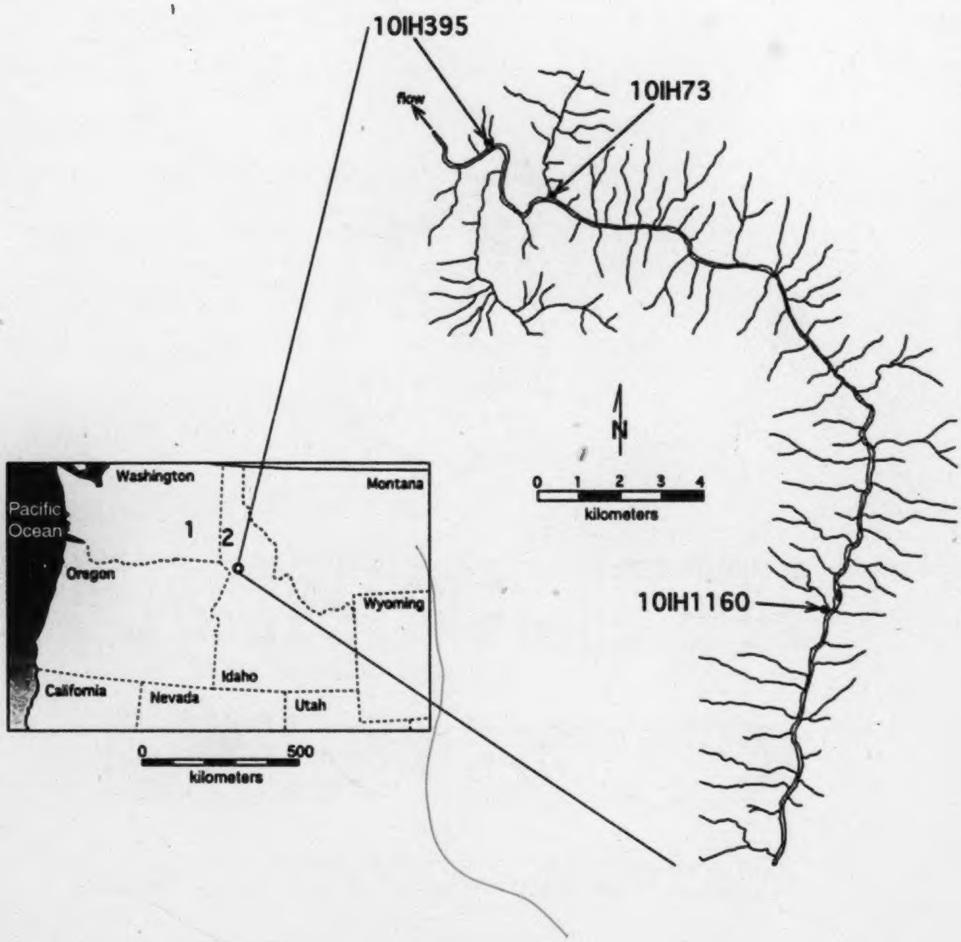
10IH395
10IH73
flow
N
0 1 2 3 4
kilometers
10IH1160
Washington
Montana
Pacific Ocean
1
2
Oregon
Wyoming
Idaho
California
Nevada
Utah
0 500
kilometers

Figure 122. Location of Lower Salmon River Canyon study area in the Pacific Northwest, USA and position of archaeological sites used in this study. Numbers correspond to localities mentioned in text: (1) Lower Snake River Canyon; (2) Clearwater River and location of the Hatwai site (an important source of data used by Ames 1988).

Site	Provenience	Method	Lab Number	Material	^{14}C age*
10IH1160	G/L18/194-210 cm	AMS	Beta-142165	wood charcoal	6,250 ±70
10IH2491	2491/50,D,L13	AMS	Beta-114806	wood charcoal	6,780 ±50
10IH395	395/28, B, L10	Conv.	Tx-9269	mussel shell	8,360 ±80
10IH73	73/279, A, L7	AMS	Beta-114952	wood charcoal	8,430 ±70
10IH1160	G/L18/205-206 cm	AMS	Beta-142166	wood charcoal	8,760 ±70
10IH1220	190-200 cm	AMS	TO-7814	soil humate	9,170 ±180
10IH73	A/SE/RC2	AMS	Beta-114949	wood charcoal	11,370 ±40
10IH73	SW/18	AMS	TO-7349	wood charcoal	11,410 ±130

Table 23. Radiocarbon ages from sites used in this study (* uncalibrated radiocarbon years before present).

Site Stratigraphy

Ten lithostratigraphic units and three pedostratigraphic units were identified during the excavation of Unit A at the Cooper's Ferry site (Figure 123). Facies interpretations, based on various characteristics of each deposit (e.g., texture, sorting, structures, allostratigraphic boundaries) point to the changing nature of late Pleistocene to early Holocene environments in the LSRC. The initial cultural occupation encountered in Unit A (CF2) is associated with the surface of a weak paleosol (S1) developed into lithostratigraphic unit 3 (LU3), which is thought to date between 11,370 and 11,410 yr BP. Following burial of the S1 surface by renewed aeolian sedimentation (LU4), early hunter-gatherers return to the site, producing component CF3. A shift to an alluvial depositional environment is represented by LU5, which contains component CF4. The expansion of a low-energy, biotically-productive alluvial floodplain is seen with the deposition of LU6 some time before 8,430 yr BP. Cultural component CF5 represents the most intensive occupation of Cooper's Ferry and occurred within an accretionary depositional environment, which buried repeated occupation of the site.

American Bar (10IH395)

Geomorphic Setting

The American Bar site is located at the lower end of the study area, exposed in a large cutbank produced by heavy machinery disturbance. Today, an alluvial fan overlies relict floodplain deposits that bear early cultural materials.

Site Stratigraphy

Five cultural components (AB1-AB5) were found within four lithostratigraphic units in excavation Unit B at the American Bar site (Figure 124). The earliest two assemblages are contained within aeolian sediments (LU11 and LU12), while the remaining cultural components are associated with sandy alluvial deposition (LU13) followed by the appearance of lower-energy alluvial floodplain sediments interfingered with alluvial fan gravels (LU14). Two radiocarbon dates provide upper limiting ages for cultural occupation of the site. A younger date of 6,070 yr BP is derived from a conventional ^{14}C date on bulk soil humate

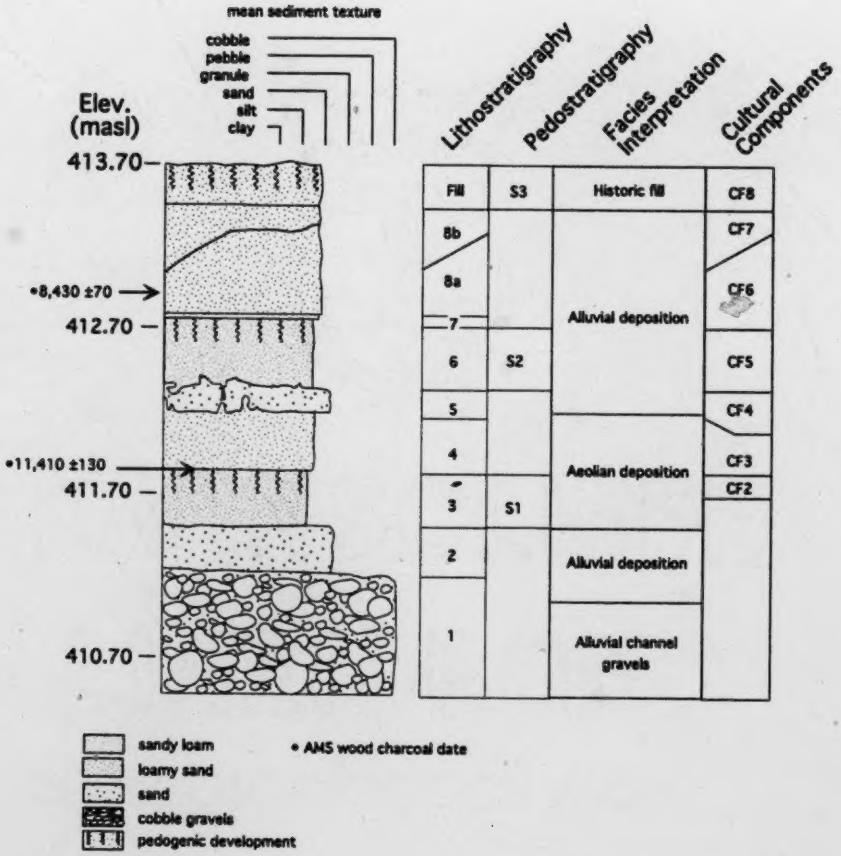
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Elev. (masl)
413.70
•8,430 ±70
412.70
•11,410 ±130
411.70
410.70
Lithostratigraphy
Pedostratigraphy
Facies Interpretation
Cultural Components
Fill
S3
Historic fill
CF8
8b
CF7
8a
CF6
7
Alluvial deposition
6
S2
CF5
5
CF4
4
CF3
Aeolian deposition
CF2
3
S1
2
Alluvial deposition
1
Alluvial channel gravels
sandy loam
loamy sand
sand
cobble gravels
pedogenic development
• AMS wood charcoal date

Figure 123. Stratigraphic record at 10IH73, Unit A.

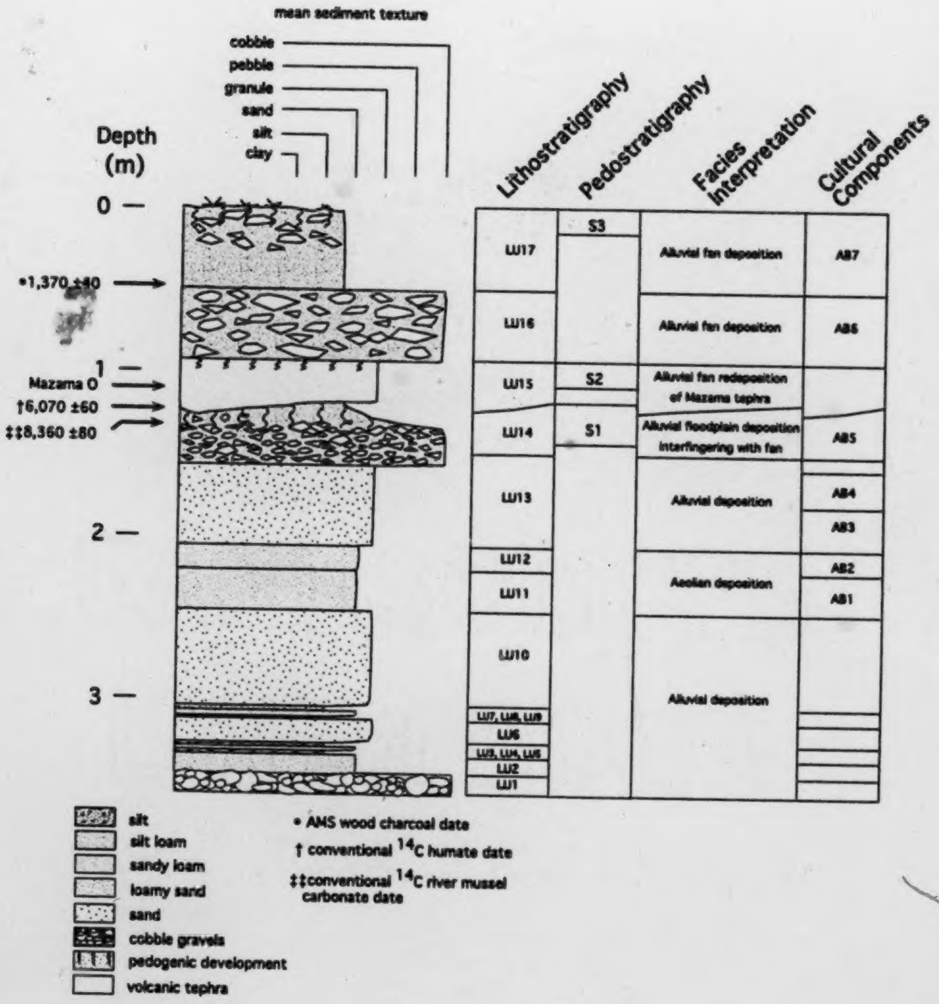
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
•1,370 ±40
Mazama O
†6,070 ±60
‡‡8,360 ±80
Lithostratigraphy
Pedostratigraphy
Facies Interpretation
Cultural Components
LU17
LU16
LU15
LU14
LU13
LU12
LU11
LU10
LU7, LU8, LU9
LU6
LU3, LU4, LU5
LU2
LU1
S3
S2
S1
Alluvial fan deposition
Alluvial fan deposition
Alluvial fan redeposition of Mazama tephra
Alluvial floodplain deposition interfingering with fan
Alluvial deposition
Aeolian deposition
Alluvial deposition
AB7
AB6
AB5
AB4
AB3
AB2
AB1
silt
silt loam
sandy loam
loamy sand
sand
cobble gravels
pedogenic development
volcanic tephra
• AMS wood charcoal date
† conventional 14C humate date
‡‡conventional 14C river mussel carbonate date

Figure 124. Stratigraphic record at 10IH395, Unit B.

collected from the surface of LU14, while a conventional ^{14}C date on river mussel shell carbonate returned an age of 8,360 yr BP. An immediate question arises concerning the accuracy of radiocarbon assays on river mussel shell carbonate, which produced dates often considered too old (e.g., Leonhardy 1970). The collection and submission of a living river mussel shell for AMS analysis at the Beta Analytic laboratory by David Sisson of the Bureau of Land Management, Cottonwood Resource Area Office, returned a age younger than A.D. 1950 (i.e., "modern") (Beta-134140) (David Sisson, written communication 2001). This date calls into question the assumption that all radiocarbon analyses on freshwater mussel shell carbonate from Plateau rivers should be considered suspect, particularly where the incorporation of old carbon into the shell building process cannot be shown. Since the cultural materials from AB5 were found in association with the dated river mussel shells, its age is considered to approximate 8,360 yr BP. The underlying alluvial and aeolian deposits associated with AB4-AB1 are not directly dated at this time. Attention should be paid to the similarity between the lower stratigraphy of American Bar's Unit B and Cooper's Ferry Unit. On the basis of this relative stratigraphic comparison, the earlier cultural components of AB1-AB4 are thought to be related to the earlier aspects of the Pioneer Period (e.g., Windust), or in the case of the local cultural sequence, related to the Cooper's Ferry I and II phases (Davis n.d.).

McCulley Creek (10IH1160)

Geomorphic Setting

The McCulley Creek site is located about 10 miles upriver of the Cooper's Ferry site, exposed in historic placer mining cuts 6 m (20') above the modern Salmon River channel. Geologically, the site was formed through the interaction of alluvial fan growth from the mouth of McCulley Creek, alluviation from the Salmon River, and colluvial inputs from the nearby canyon slope.

Site Stratigraphy

Fourteen lithostratigraphic and two pedostratigraphic units form the basic stratigraphic framework for the McCulley Creek site (Figure 125). Alluvial processes from both the Salmon River and tributary discharge of McCulley Creek created a stratified sequence of deposits. Aeolian deposition is seen only at the

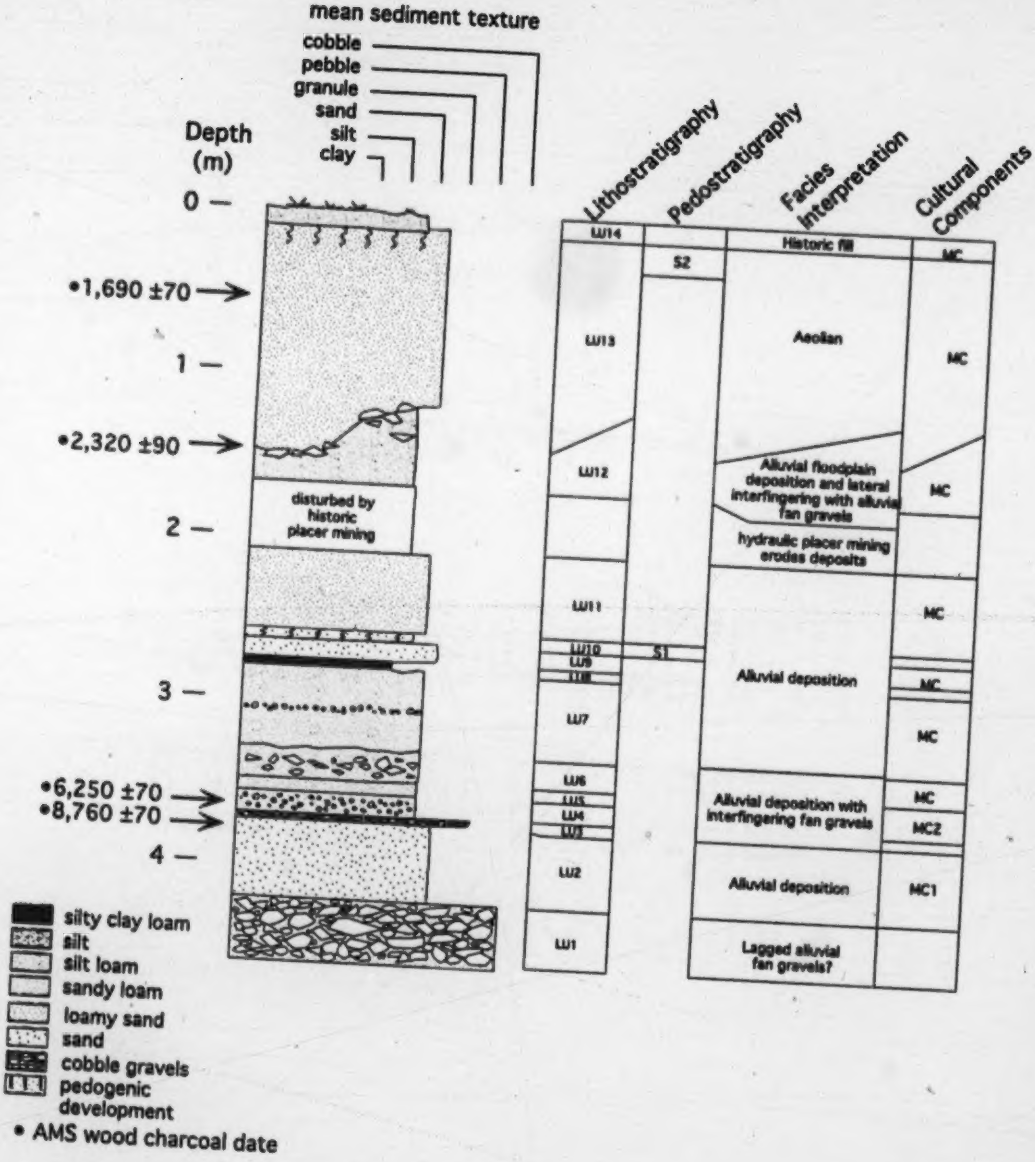
mean sediment texture
cobble
pebble
granule
sand
silt
clay
Depth (m)
0
1
2
3
4
•1,690 ±70
•2,320 ±90
•6,250 ±70
•8,760 ±70
disturbed by historic placer mining
Lithostratigraphy
Pedostratigraphy
Facies Interpretation
Cultural Components
LU14
LU13
LU12
LU11
LU10
LU9
LU8
LU7
LU6
LU5
LU4
LU3
LU2
LU1
S2
S1
Historic fill
Aeolian
Alluvial floodplain deposition and lateral interfingering with alluvial fan gravels
hydraulic placer mining erodes deposits
Alluvial deposition
Alluvial deposition with interfingering fan gravels
Alluvial deposition
Lagged alluvial fan gravels?
MC
MC
MC
MC
MC
MC
MC
MC2
MC1
silty clay loam
silt
silt loam
sandy loam
loamy sand
sand
cobble gravels
pedogenic development
• AMS wood charcoal date

Figure 125. Composite stratigraphic record at 10IH1160.

top of the site profile, dating within the last 2,000 yr BP or so. The two early Holocene-age cultural components (MC1 and MC2) are contained within three lithostratigraphic units (LU2 and LU4-LU5). The presence of radiocarbon dates of 8,760 and 6,250 yr BP on either side of a thin layer of pebble gravels (LU3) suggests that an erosional unconformity separates the early cultural components. Artifacts associated with either component were not found as a lagged assemblage on top of or directly beneath the surface of LU3, thus answering an obvious question of the taphonomic integrity of the components.

Methods of Archaeological Data Collection

Excavation Methods

Archaeological excavations were conducted at seven sites between 1997 and 2000, involving field school students from the University of Alberta and the University of Idaho. Because group size was relatively small (from 3 to 14 students excavating at a given site), and care was used to recover large quantities of archaeological materials *in situ*, only a small portion of any given site could be investigated during each field season. Early cultural components with assemblages suitable for inclusion in this study came from only three of the seven sites investigated. At these three sites, excavation units encountering early cultural components consisted of three 2 x 2 meter pits and one 1 x 2 meter pit. As a result, interpretations on the nature of site activities must be made with caution considering the relatively small sample size of the excavations.

The Early Cultural Dataset

Artifactual and subsistence data are gathered from ten cultural components contained in three study area archaeological sites (Tables 24-27). Archaeological materials were grouped into assemblages for the sake of analysis. Divisions were made on the basis of visible geological boundaries separating different occupations, technological similarity--here, projectile point styles were used to break out different cultural occupations and their toolkits. Twelve analytical assemblages, corresponding to cultural components CF2 to CF5 at Cooper's Ferry, AB1 to AB5 at American Bar, and MC1 and MC2 at the McCulley Creek site.

10IH73	CF2		CF3		CF4		CF5	
	n	%	n	%	n	%	n	%
Antler Flaker	0	0	0	0	0	0	0	0
Antler Flesher	0	0	0	0	0	0	0	0
Antler Haft	0	0	0	0	0	0	0	0
Biface	2	14.3	2	7.1	5	25	31	22.6
Blade	2	14.3	0	0	2	10	5	3.6
Bone Tool	0	0	0	0	0	0	0	0
Burin	0	0	0	0	0	0	0	0
Cobble Tool	0	0	1	3.6	0	0	2	1.5
Core	2	14.3	4	14.3	2	10	9	6.6
Fish Gorge	0	0	0	0	0	0	0	0
Groundstone	0	0	0	0	0	0	2	1.5
Hammerstone	1	3.6	1	1.8	0	0	3	1.1
Modified Flake	0	0	14	50	9	45	63	46
Point	4	28.6	3	10.7	2	10	9	6.6
Uniface	3	21.4	3	10.7	0	0	13	9.5
Total	14	96.4	28	98.2	20	100	137	98.9

Table 24. Lithic and bone tool frequencies by quantity (n) and percentage (%) in early cultural assemblages at the Cooper's Ferry site (10IH73), Unit A.

10IH395	AB1		AB3		AB4		AB5	
	n	%	n	%	n	%	n	%
Antler Flaker	0	0	0	0	0	0	0	0
Antler Flesher	0	0	0	0	0	0	0	0
Antler Haft	0	0	0	0	0	0	0	0
Biface	1	50	0	0	5	55.6	4	16
Blade	0	0	0	0	0	0	0	0
Bone Tool	0	0	0	0	0	0	1	2
Burin	0	0	0	0	0	0	0	0
Cobble Tool	0	0	0	0	0	0	0	0
Core	0	0	0	0	0	0	0	0
Fish Gorge	0	0	0	0	0	0	0	0
Groundstone	0	0	0	0	0	0	0	0
Hammerstone	0	0	0	0	2	22.2	2	4
Modified Flake	1	50	1	33.3	1	11.1	10	40
Point	0	0	2	66.7	1	11.1	6	24
Uniface	0	0	0	0	0	0	2	8
Total	2	100	3	100	9	100	25	94

Table 25. Lithic and bone tool frequencies by quantity (n) and percentage (%) in early cultural assemblages at the American Bar site (10IH395), Unit B.

10IH1160	MC1		MC2	
	n	%	n	%
Antler Flaker	0	0	0	0
Antler Flesher	0	0	0	0
Antler Haft	0	0	0	0
Biface	1	16.7	3	42.9
Blade	0	0	0	0
Bone Tool	0	0	0	0
Burin	0	0	0	0
Cobble Tool	0	0	0	0
Core	1	16.7	0	0
Fish Gorge	1	9.1	0	0
Groundstone	0	0	0	0
Hammerstone	0	0	0	0
Modified Flake	1	16.7	1	14.3
Point	2	33.3	2	28.6
Uniface	0	0	1	14.3
Total	6	92.4	7	100

Table 26. Lithic and bone tool frequencies by quantity (n) and percentage (%) in early cultural assemblages at the McCulley Creek site (10IH1160), Unit G.

10IH73		CF1			CF2			CF3			CF4			CF5	
	wt.	n	%	wt.	n	%	wt.	n	%	wt.	n	%	wt.	n	%
Terrestial Bone	1.0		100.0	18.1		79.4	29.3		74.0	27.1		76.1	363.8		53.6
Fish Bone		0			0			15			5			127	
M.Shell	0.0		0.0	2.2		9.6	9.0		22.7	7.0		19.7	295.9		43.6
S.Shell	0.0		0.0	2.5		11.0	1.3		3.3	1.5		4.2	19.6		2.9
Total	1.0		100.0	22.8		100.0	39.6		100.0	35.6		100.0	679.3		100.0

10IH395		AB1			AB2			AB3			AB4			AB5	
	wt.	n	%	wt.	n	%	wt.	n	%	wt.	n	%	wt.	n	%
Terrestial Bone	33.4		59.4	5.4		38.3	7.9		15.1	37.2		60.0	32.2		35.9
Fish Bone		0			0			0			0			0	
M.Shell	22.3		39.7	0.9		6.4	39.8		76.0	11.0		17.7	44.7		49.8
S.Shell	0.5		0.9	7.8		55.3	4.7		9.0	13.8		22.3	12.9		14.4
Total	56.2		100.0	14.1		100.0	52.4		100.0	62.0		100.0	89.8		100.0

10IH1160		MC1			MC2	
	wt.	n	%	wt.	n	%
Terrestial Bone	61.0		73.8	83.0		42.9
Fish Bone		2			0	
M.Shell	21.2		25.6	103.3		53.4
S.Shell	0.5		0.6	7.2		3.7
Total	82.7		100.0	193.5		100.0

Table 27. Faunal materials in early assemblages at study area sites. Quantities of terrestrial bone, mussel shell (M.Shell), and land snail shell (S.Shell) are reported as weight (wt.) in grams; quantities of fish bone are shown as total individual vertebra (n). Percentages reflect the proportion of faunal remains by weight only, excluding fish bone.

In each of these assemblages, the total number and relative percentages of 10 tool classes and four subsistence classes were tablulated.

Lithic Technology

Bifaces: bifaces are defined as, "those objective pieces with two sides that meet to form a single edge that circumscribes the entire artifact. Both sides are called faces and both show evidence of previous flake removals" (Andrefsky 1998:172). Two main categories of bifaces are recognized in this study. The first, termed *simple bifaces* (hereafter shortened to *bifaces*), include those lithic pieces that show varying degrees of bifacial reduction, producing a wide range of metric proportions. Although not specifically addressed in this study, bifaces are thought to serve as utilitarian cutting, chopping, sawing, incising and even scraping tools, and are a common component of prehistoric Plateau assemblages. Potentially, bifaces were hafted or employed in a freehand fashion.

Projectile points are considered as a special class of bifaces and include modification and morphological features that enable them to be hafted and thrust, thrown, or otherwise propelled at game animals. While projectile points were likely used to perform many of the utilitarian tasks required of simple bifaces (Beck and Jones 1993), their role as hafted lithic weapons is notably visible in the archaeological record of the Plateau region. Within the early assemblages of the LSRC study area, projectile points appear mainly as stemmed and lanceolate forms only, with Cold Spring Side Notched points being the only exception (Butler 1962, 1969; Davis n.d.). These point styles are generally classified as part of the Western Stemmed Tradition (see Bryan 1980) and are specifically identified at the Lind Coulee site (Daugherty 1956), and as defining aspects of the Windust and Cascade phases (Leonhardy and Rice 1970).

Blades and Modified Flakes: considered expedient tools are characterized by a simple design and limited use-life. Typically, these tools are created and disposed of at the place of their use. In this study, lithic blades and modified flakes represent the expedient tool category. Blades are the result of purposeful core preparation and reduction that produce regularized flakes, often with central or parallel ridges. Modified flakes are defined as any debitage piece that retains evidence of use in the form of wear, polish and/or microfracturing (e.g. Hayden 1979; Keeley 1979). While trampling of debitage was shown to produce a kind of fracturing that is argued to be confused with use-wear traces (e.g., Flenniken and Haggerty 1979; Gifford-Gonzalez et al. 1985; Nielsen 1991), careful attention was paid to the selection of only those pieces that showed a polished gloss, regular bifacial or unifacial microfracturing, or abrasion/striations. These kinds of edge wear are not typically associated with post-depositional alteration, such as that produced by trampling.

Cobble Tools: defined here as any cobble-sized lithic clast that is either bifacially or unifacially flaked to produce a working edge. Cobble tools are typically larger tools and are were likely used for more vigorous tasks, such as chopping, cutting, and sawing.

Cores: masses of lithic material, bone, or ivory subjected to a reduction process in which smaller flakes or chips of material are removed, in various methods, in greater or lesser degrees of control. Cores can occur in many forms, reflecting the production goals of the knapper. The resulting flakes can be used for a wide variety of tasks or provide the starting point for the production of other tools.

Unifaces: these artifacts are defined as lithic pieces that show flaking in a single direction to produce an edge on only one face. The working edge of a uniface may be steep or low-angled, convex or concave in form. These tools likely operated as scrapers and planes on a variety of materials such as bone, antler, hide or wood.

Bone and Antler Tools

Defined here as alteration of bone or antler into a form to perform a task or job on its own, or as part of a composite tool. While a range of bone and antler tools were found in early Holocene-age assemblages, bone technology in sites along the LSRC is limited to single bone point recovered from the American Bar site (component AB5). Although Butler (1962) reports the discovery of several bone and antler tools, including portions of antler flakers, fleshers and a haft or handle, possibly for a knife, from the Weis Rockshelter site, this assemblage was excluded from this study because of its location away from the Lower Salmon River riparian zone.

Subsistence

Because a detailed zooarchaeological analysis was not conducted on recovered faunal materials as part of this study, discussion of changing patterns of subsistence behavior will be presented in relative terms. Of particular interest is the quantitative distribution of terrestrial and aquatic remains through time. Vertebrates are largely represented in study area sites as burned and unburned bone fragments, with tooth fragments rounding out the sum of faunal remains. Shells of river mussels and land snails are commonly found in association with cultural materials, pointing to their inclusion in the diets of early hunter-gatherers. The latter are not typically been considered an important aspect of Plateau subsistence; however, recent work at the McCulley Creek site revealed a late Holocene pit feature that contained shells and shell fragments from at least 125 land snails (L.G. Davis, unpublished data). Therefore, they will be considered a possible subsistence resource in this study.

Evidence of plant use is elusive in LSRC sites thusfar, likely related to the data recovery methods employed and to poor organic preservation in late Pleistocene to middle Holocene-age deposits. The use of extensive macrobotanical and phytolith studies in future efforts should provide valuable insights into the kinds of plants that were being exploited by early peoples. Technological evidence of plant processing is potentially represented by groundstone implements and hammerstones. Alternative viewpoints regarding the function of edge-ground cobbles (e.g., Crabtree and Swanson 1968) increases the ambiguity that surrounds the issue of groundstone tool use among early hunter-gatherers, particularly where manos, metates and other more-obvious plant processing tools are absent. Hammerstones and groundstone implements may be used to extract bone marrow, or process dried meat, shellfish and snails, as well as conduct a wide range of lithic reduction tasks, which confound the issue entirely. Thus, in the absence of indepenent data regarding the presence of plant material in early sites, little may be inferred from the presence of these utilitarian tools.

Results of Analyses

First-Order Observations

Diachronic Frequency of Tool Types

The Cooper's Ferry site produced the largest tool and faunal assemblage as well as the greatest number of hearth features (Table 24, Figure 126). In nearly all cases, the total number of lithic tools increased with time, with an exception seen between assemblages CF3 and CF4. The trend of increasing tool frequency is also seen at American Bar with projectile points, modified flakes and bifaces comprising the largest portion of assemblage AB5. A single bone point was also recovered from AB5. Assemblage MC2 is differentiated from MC1 by its increases in bifaces, modified flakes and unifaces.

Technological Trends

Changes in projectile point technology also occur through time in the study assemblages. At Cooper's Ferry, Lind-Coulee stemmed points dominate the CF2 assemblage, giving way to a more diverse collection of Windust-type stemmed points in CF4. At the McCulley Creek site, stemmed points with a lenticular cross-section, similar to both Windust (D. Rice 1972:Figure 4c) and Eden points (Frison 1978) are found in assemblage MC1. Leaf-shaped Cascade points occur exclusively in MC2. Although Cascade points were the only point form encountered at the American Bar site, stratigraphically-lower components lacking points may relate to earlier occupations at other sites (e.g., Cooper's Ferry I and II (Davis n.d.)). Paleoarchaic stemmed and lanceolate points, falling under the Cooper's Ferry I and II phase designations (Davis n.d.), disappear from LSRC sites by ca. 8,500 yr BP and are immediately replaced by the appearance of Cascade points, marking the beginning of the Archaic. This transition is not as clearly defined as it may appear. A few unstemmed leaf-shaped lanceolate point specimens are seen in the Windust-age component at Windust Caves (H. Rice 1965:Figure 17); eventually these point types dominate the archaeological record for a time. This same process of gradual projectile point replacement is seen at Cooper's Ferry, as stemmed points are replaced by Cascade type leaf-shaped points in CF5, (Davis and Schweger n.d.:Figure 109).

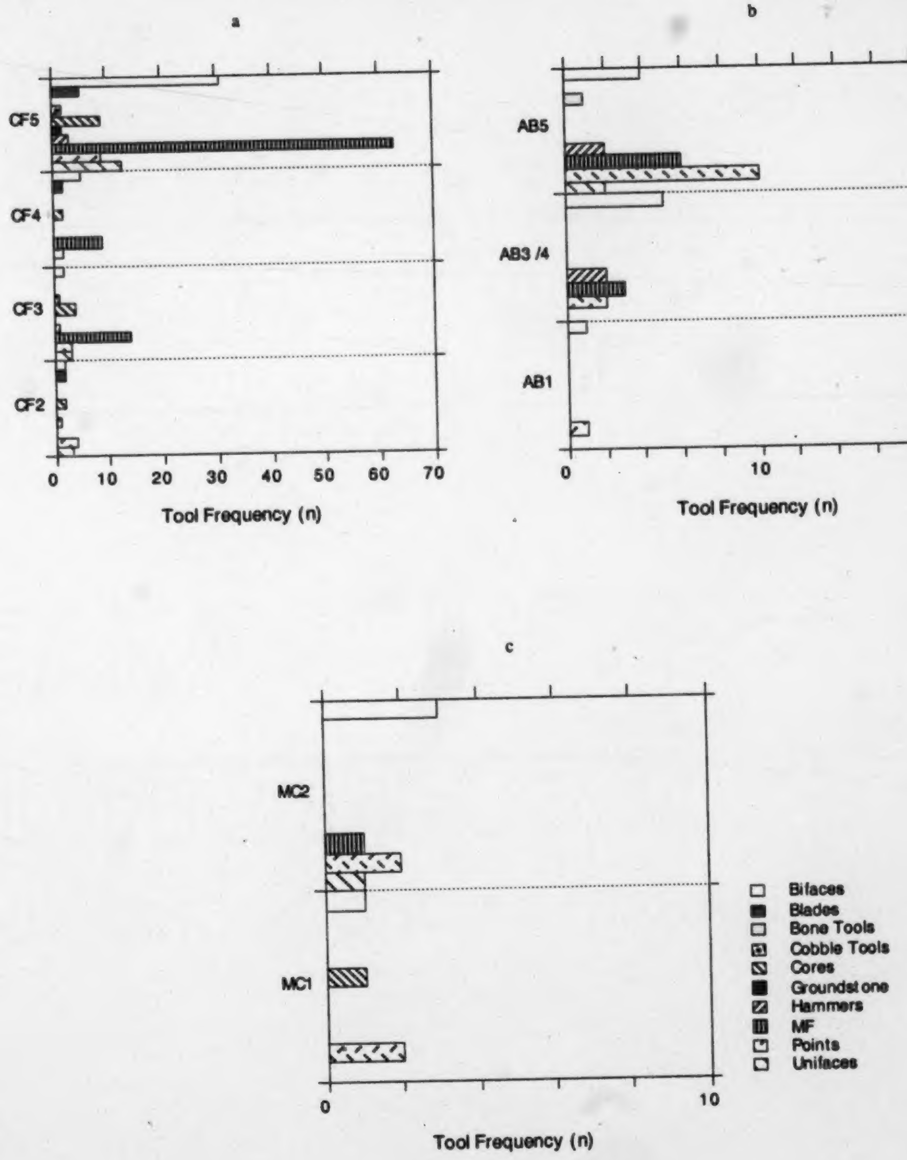

Figure 126. Frequency plots of lithic and bone tool quantities (n) in early cultural assemblages at the Cooper's Ferry site (a) American Bar site(b) and McCulley Creek site (c).

Subsistence Trends

Changing frequencies of faunal remains point to a shift in subsistence practices during the late Pleistocene to early Holocene (Table 27). One particularly interesting trend is seen in the rise of river mussel use at all sites (Figures 127 and 128). By 8,500 yr BP, hunter-gatherers were integrating freshwater shellfish into their diets at relatively high frequencies. In some cases, mussel shell outweighs bone (e.g., MC2, AB3/4 and AB5). Increasing use of aquatic species is further reflected in rising quantities of fish vertebra at Cooper's Ferry (Figure 128b).

Activity Trends

Although the spatial perspective on LP-EH canyon occupation is limited to single 2 x 2 m or 1 x 2 m test pits, and are more suited to viewing the stratigraphic record of culture and its change, the relative intensity of site use can be seen from the density of artifacts and activity features within different stratigraphic units. Diachronic comparisons of these data are useful in a relative sense as they may reflect general trends in site-level human activities.

Evaluating Organizational Strategies

Archaeological patterns of logistical organization, reflected in the structure and content of artifact assemblages, can be viewed as indicators of how humans interacted with their environmental context. One measure of logistical organization is found in the tests of assemblage richness and diversity. Kaufman's (1998) use of the "jackknife technique" (Zahl 1977) on archaeological data provides a way to compare the frequencies of sets of taxa (e.g., artifact types) to establish statistical values of richness and evenness for populations (or assemblages) in a manner that avoids traditional problems tied to sample size and significance. Measures of artifact assemblage richness and evenness were made by Ames (1988) on 13 southern Plateau LP-MH archaeological components. Magurran (1988) defines richness indices as the number of different species, taxa, or classes of a given aspect in a defined sampling unit, while evenness indicies are said to describe, "the distribution of species abundances or the relative frequencies of individuals within each of the species or classes" (Kaufman (1998:77). Richness and evenness of early artifact

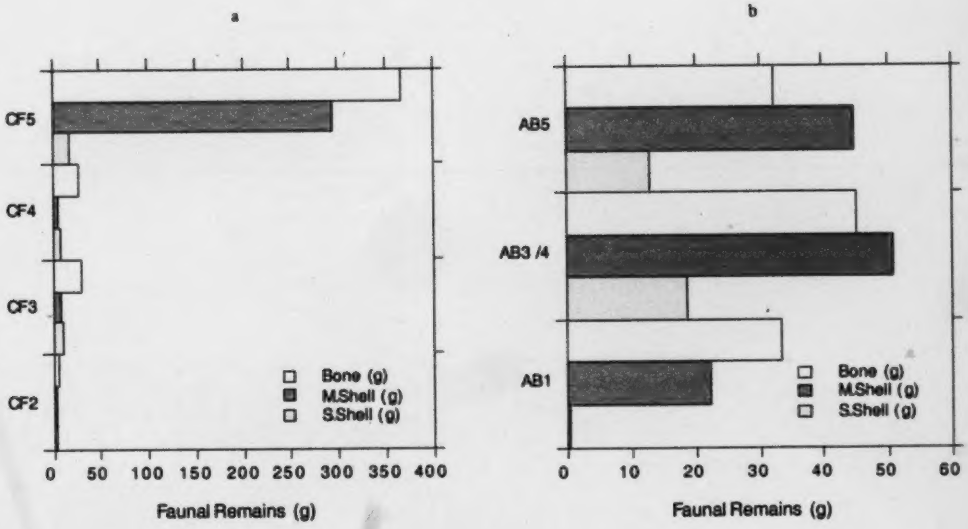

Figure 127. Frequency plot of faunal remains by weight (g = grams) in cultural components at the Cooper's Ferry site (a) and the American Bar site (b).

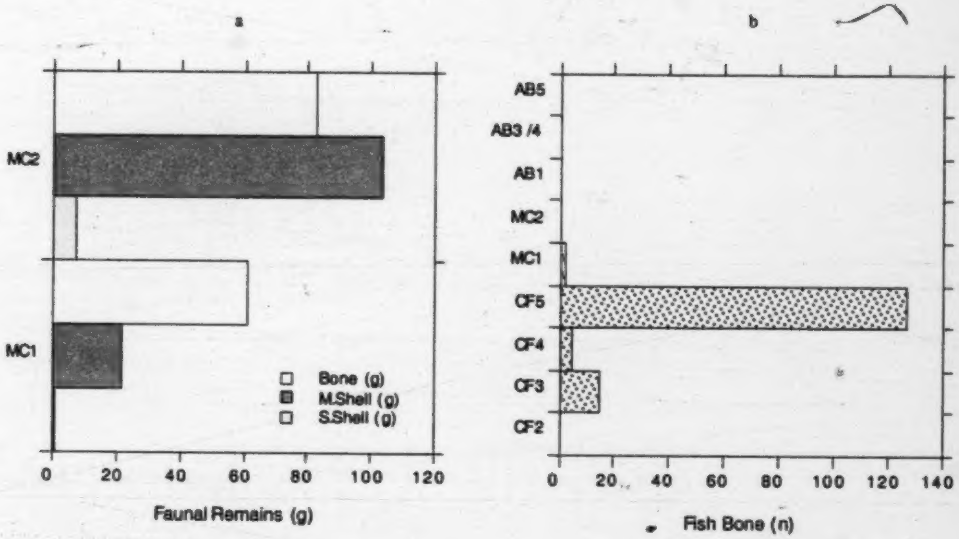

Figure 128. Frequency plot of faunal remains by weight (g = grams) in cultural components at the McCulley Creek site (a) and quantity (n) of fish bone (i.e., total individual vertebra) among all cultural components at all study sites (b).

assemblages from the LSRC will be provided using the jackknife technique as outlined in Kaufman (1998), with the data and results provided in Tables 28-35.

Site Function Through Time

Drawing from the view that patterning in artifact assemblages directly relates to the economic activities of hunter-gatherers, Kaufmann (1998:81) provides an example of how richness and evenness values for late Paleolithic settlement patterns might be interpreted within Binford's (1980) model of residential and logistical organization:

> The basic assumption is that sites with many tool classes, which are evenly distributed within the assemblage (expressed as high richness and evenness values), most likely represent multipurpose base camps organized within a logistical strategy. Such assemblages would also be indicative of multipurpose occupations operating within a residential system of mobility. Sites with low richness values, and which are dominated by one or two tool classes (reflected in low evenness), represent specialized activity camps.

Using these guiding statements, a clear distinction is seen between LP-EH cultural assemblages in the LSRC (Figure 129). Low richness and evenness in assemblages CF2, CF3, AB3/4 and MC1 fall within the range expected for hunter-gatherers employing a collector strategy. The high evenness and low richness of assemblages CF4, CF5 and AB5 places them within a foraging mode of residential and logistical mobility. Interestingly, these strategic divisions also fall along temporal lines, with the exception of MC2, with the earlier Paleoarchaic components clustered at the collector end of the spectrum and the late Windust and Cascade assemblages found at the forager end. In the process of testing his hypothesis regarding early Holocene foraging strategies, Ames (1988) reports this same pattern. Thus,

Groups	S_T	S_1	S_2	S_3	S_4	S_5	S_6
Biface	2	0	2	2	2	2	2
Blade	2	2	0	2	2	2	2
Core	2	2	2	0	2	2	2
Modified Flake	7	7	7	7	0	7	7
Point	4	4	4	4	4	0	4
Uniface	3	3	3	3	3	3	0
N	20	18	18	18	13	16	17
θ_T, θ_i	1.66	1.49	1.49	1.49	1.56	1.46	1.46
Φ_i		1.06	1.06	1.06	0.60	1.26	0.16
mean Φ	0.87						
k	6	5	5	5	5	5	5
Richness							
θ_T, θ_i	1.34	1.18	1.18	1.18	1.39	1.25	1.21
Φ_i		2.16	1.18	1.18	0.35	1.93	1.40
Mean Φ_i	1.37	(Jackknife value for Richness)					
Evenness							
θ_T, θ_i	1.80	2.16	2.16	2.16	1.21	2.13	2.19
Φ_i		-0.03	-0.03	-0.03	4.70	0.10	-0.19
Mean Φ_i	0.75	(Jackknife value for Evenness)					
STD Φ	3.58						
SE Φ	1.35						
Mean S_T	3.33	3.00	3.00	3.00	2.17	2.67	2.83

Table 28. Results of Jackknife analysis for richness and evenness of the CF2 lithic tool assemblage, Cooper's Ferry site. Analysis conducted on a combination of assemblage data from LU3, Unit A and Butler's (1969) Layer 8 and 9 assemblage data (see Davis and Schweger n.d. for correlation of cultural stratigraphy between excavation units). Symbols and abbreviations follow Kaufmann (1998) and include: N = sample size; S_T = total number of analytical sets (i.e., S = species); S_1, S_2, S_3, etc. = analytical sets; θ_T = the estimate of heterogeneity for each of the total assemblages (averaged from the individual estimates for heterogeneity for each analytical set (θ_i)); Φ_i = the pseudovalue for each analytical set; k = analytical groups included in each analytical set; STD Φ = standard deviation of pseudovalue mean; SE Φ = standard error of pseudovalue mean.

Groups	S_T	S_1	S_2	S_3	S_4	S_5	S_6
Biface	4	0	4	4	4	4	4
Cobble Tool	1	1	0	1	1	1	1
Core	4	4	4	0	4	4	4
Modified Flake	16	16	16	16	0	16	16
Point	3	3	3	3	3	0	3
Uniface	3	3	3	3	3	3	0
N	31	27	30	27	15	28	28
θ_T, θ_i	1.21	1.20	1.33	1.20	1.53	1.23	1.23
Φ_i		0.02	-0.76	0.02	-1.94	-0.16	-0.16
mean Φ	-0.50						
k	6	5	5	5	5	5	5
Richness							
θ_T, θ_i	1.08	0.96	0.91	0.96	1.29	0.94	0.94
Φ_i		1.65	1.16	0.72	-0.35	2.68	0.94
Mean Φ_i	1.13	(Jackknife value for Richness)					
Evenness							
θ_T, θ_i	4.95	5.32	5.10	5.32	1.50	5.28	1.49
Φ_i		3.11	4.19	3.11	22.18	3.28	22.23
Mean Φ_i	9.68	(Jackknife value for Evenness)					
STD Φ	4.76						
SE Φ	1.80						
Mean S_T	5.17	4.50	5.00	4.50	2.50	4.67	4.67

Table 29. Results of Jackknife analysis for richness and evenness of the CF3 lithic tool assemblage, Cooper's Ferry site. Analysis conducted on a combination of assemblage data from LU4, Unit A and Butler's (1969) Layer 7 assemblage data (see Davis and Schweger n.d. for correlation of cultural stratigraphy between excavation units). Symbols and abbreviations follow Kaufmann (1998) and include: N = sample size; S_T = total number of analytical sets (i.e., S = species); S_1, S_2, S_3, etc. = analytical sets; θ_T = the estimate of heterogeneity for each of the total assemblages (averaged from the individual estimates for heterogeneity for each analytical set (θ_i)); Φ_i = the pseudovalue for each analytical set; k = analytical groups included in each analytical set; STD Φ = standard deviation of pseudovalue mean; SE Φ = standard error of pseudovalue mean.

Groups	S_T	S_1	S_2	S_3	S_4	S_5	S_6	S_7
Biface	12	0	12	12	12	12	12	12
Blade	3	3	0	3	3	3	3	3
Cobble Tool	1	1	1	0	1	1	1	1
Core	2	2	2	2	0	2	2	2
Modified Flake	29	29	29	29	29	0	29	29
Point	8	8	8	8	8	8	0	8
Uniface	1	1	1	1	1	1	1	0
N	56	44	53	55	54	27	48	55
θ_T, θ_i	1.37	1.08	1.23	1.30	1.26	1.40	1.12	1.30
Φ_i		2.02	1.00	0.46	0.76	-0.23	1.75	0.46
mean Φ	0.89							
k	7	6	6	6	6	6	6	6
Richness								
θ_T, θ_i	0.94	0.90	0.82	0.81	0.82	1.15	0.87	0.81
Φ_i		1.12	1.31	0.90	0.77	-0.87	2.60	1.15
Mean Φ_i	**1.00**	(Jackknife value for Richness)						
Evenness								
θ_T, θ_i	19.10	16.07	18.43	18.89	18.66	9.04	17.19	18.89
Φ_i		37.32	23.15	20.42	21.77	79.47	30.60	20.42
Mean Φ_i	**33.31**	(Jackknife value for Evenness)						
STD Φ	4.78							
SE Φ	1.69							
Mean S_T	8.00	6.29	7.57	7.86	7.71	3.86	6.86	7.86

Table 30. Results of Jackknife analysis for richness and evenness of the CF4 lithic tool assemblage, Cooper's Ferry site. Analysis conducted on a combination of assemblage data from LU5, Unit A and Butler's (1969) Layer 6 assemblage data (see Davis and Schweger n.d. for correlation of cultural stratigraphy between excavation units). Symbols and abbreviations follow Kaufmann (1998) and include: N = sample size; S_T = total number of analytical sets (i.e., S = species); S_1, S_2, S_3, etc. = analytical sets; θ_T = the estimate of heterogeneity for each of the total assemblages (averaged from the individual estimates for heterogeneity for each analytical set (θ_i)); Φ_i = the pseudovalue for each analytical set; k = analytical groups included in each analytical set; STD Φ = standard deviation of pseudovalue mean; SE Φ = standard error of pseudovalue mean.

Tool Type	S_T	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Biface	37	0	37	37	37	37	37	37	37
Blade	6	6	0	6	6	6	6	6	6
Cobble Tool	2	2	2	0	2	2	2	2	2
Core	9	9	9	9	0	9	9	9	9
Groundstone	2	2	2	2	2	0	2	2	2
Modified Flake	77	77	77	77	77	77	0	77	77
Point	8	8	8	8	8	8	8	0	8
Uniface	13	13	13	13	13	13	13	13	0
N	154	117	148	152	145	152	77	146	141
θ_T, θ_i	1.46	1.19	1.34	1.41	1.31	1.41	1.53	1.32	1.27
Φ_i		2.12	0.79	0.36	1.02	0.36	-0.49	0.95	1.27
mean Φ	0.80								
k	8	7	7	7	7	7	7	7	7
Richness									
θ_T, θ_i	0.64	0.65	0.58	0.57	0.58	0.57	0.80	0.58	0.59
Φ_i		0.63	1.13	1.18	1.09	1.18	-0.43	1.10	1.03
Mean Φ_i	**0.86**	(Jackknife value for Richness)							
Evenness									
θ_T, θ_i	24.22	23.92	24.70	24.40	24.87	24.40	11.10	24.82	25.00
Φ_i		26.32	20.81	22.91	19.66	22.91	116.02	20.01	18.70
Mean Φ_i	**33.42**	(Jackknife value for Evenness)							
STD Φ	6.20								
SE Φ	2.19								
Mean S_T	19.25	14.63	18.50	19.00	18.13	19.00	9.63	18.25	17.63

Table 31. Results of Jackknife analysis for richness and evenness of the CF5 lithic tool assemblage, Cooper's Ferry site. Analysis conducted on a combination of assemblage data from LU6, Unit A and Butler's (1969) Layer 5 assemblage data (see Davis and Schweger n.d. for correlation of cultural stratigraphy between excavation units). Symbols and abbreviations follow Kaufmann (1998) and include: N = sample size; S_T = total number of analytical sets (i.e., S = species); S_1, S_2, S_3, etc. = analytical sets; θ_T = the estimate of heterogeneity for each of the total assemblages (averaged from the individual estimates for heterogeneity for each analytical set (θ_i)); Φ_i = the pseudovalue for each analytical set; k = analytical groups included in each analytical set; STD Φ = standard deviation of pseudovalue mean; SE Φ = standard error of pseudovalue mean.

Tool Type	S_T	S_1	S_2	S_3
Biface	5	0	5	5
Modified Flake	2	2	0	2
Point	3	3	3	0
N	10	5	8	7
θ_r, θ_i	1.03	0.67	0.66	0.60
Φ_i		1.07	1.10	1.29
mean Φ	1.16			
k	3	2	2	2
Richness				
θ_r, θ_i	0.95	0.89	0.71	0.76
Φ_i		1.06	1.43	1.33
Mean Φ_i	**0.48**	(Jackknife value for Richness)		
Evenness				
θ_r, θ_i	1.49	1.00	1.62	1.54
Φ_i		2.47	1.22	1.37
Mean Φ_i	**0.63**	(Jackknife value for Evenness)		
STD Φ	0.84			
SE Φ	0.49			
Mean S_T	1.25	0.63	1.00	0.88

Table 32. Results of Jackknife analysis for richness and evenness of the combined AB3 and AB4 lithic tool assemblage, American Bar site, Unit B. Symbols and abbreviations follow Kaufmann (1998) and include: N = sample size; S_T = total number of analytical sets (i.e., S = species); S_1, S_2, S_3, etc. = analytical sets; θ_T = the estimate of heterogeneity for each of the total assemblages (averaged from the individual estimates for heterogeneity for each analytical set (θ_ι)); Φ_i = the pseudovalue for each analytical set; k = analytical groups included in each analytical set; STD Φ = standard deviation of pseudovalue mean; SE Φ = standard error of pseudovalue mean.

Groups	S_T	S_1	S_2	S_3	S_4
Biface	4	0	4	4	4
Modified Flake	10	10	0	10	10
Point	6	6	6	0	6
Uniface	2	2	2	2	0
N	22	18	12	16	20
θ_T, θ_i	1.24	0.94	1.01	0.90	1.03
Φ_i		2.15	0.92	1.36	0.84
mean Φ	1.32				
k	4.00	3.00	3.00	3.00	3.00
Richness					
θ_T, θ_i	0.85	0.71	0.87	0.75	0.67
Φ_i		1.29	0.81	1.16	1.40
Mean Φ_i	**1.17**	(Jackknife value for Richness)			
Evenness					
θ_T, θ_i	16.76	14.04	9.27	12.57	15.43
Φ_i		24.95	39.23	29.34	20.77
Mean Φ_i	**28.57**	(Jackknife value for Evenness)			
STD Φ	1.68				
SE Φ	0.75				
Mean S_T	5.5	4.5	3	4	5

Table 33. Results of Jackknife analysis for richness and evenness of the AB5 lithic tool assemblage, American Bar site, Unit B. Symbols and abbreviations follow Kaufmann (1998) and include: N = sample size; S_T = total number of analytical sets (i.e., S = species); S1, S2, S3, etc. = analytical sets; θ_T = the estimate of heterogeneity for each of the total assemblages (averaged from the individual estimates for heterogeneity for each analytical set (qi)); Fi = the pseudovalue for each analytical set; k = analytical groups included in each analytical set; STD F = standard deviation of pseudovalue mean; SE Φ = standard error of pseudovalue mean.

Tool Type	S_T	S_1	S_2	S_3
Biface	1	0	1	1
Core	1	1	0	1
Point	2	2	2	0
N	4	3	3	2
θ_T, θ_i	1.04	0.64	0.64	0.69
Φ_i		1.21	1.21	1.04
mean Φ	1.15			
k	3	2	2	2
Richness				
θ_T, θ_i	1.50	1.15	1.15	1.41
Φ_i		2.19	2.19	1.67
Mean Φ_i	**0.76**	(Jackknife value for Richness)		
Evenness				
θ_T, θ_i	0.59	0.63	0.63	0.39
Φ_i		0.50	0.50	0.99
Mean Φ_i	**0.25**	(Jackknife value for Evenness)		
STD Φ	0.85			
SE Φ	0.49			
Mean S_T	0.50	0.38	0.38	0.25

Table 34. Results of Jackknife analysis for richness and evenness of the MC1 lithic tool assemblage, McCulley Creek site, Unit G. Symbols and abbreviations follow Kaufmann (1998) and include: N = sample size; S_T = total number of analytical sets (i.e., S = species); S1, S2, S3, etc. = analytical sets; θ_T = the estimate of heterogeneity for each of the total assemblages (averaged from the individual estimates for heterogeneity for each analytical set (qi)); Fi = the pseudovalue for each analytical set; k = analytical groups included in each analytical set; STD F = standard deviation of pseudovalue mean; SE Φ = standard error of pseudovalue mean.

Groups	S_T	S_1	S_2	S_3	S_4
Biface	3	0	3	3	3
Modified Flake	1	1	0	1	1
Point	2	2	2	0	2
Uniface	1	1	1	1	0
N	7	4	6	5	6
θ_T, θ_i	1.28	1.04	1.01	0.95	1.01
Φ_i		1.99	1.06	1.31	1.06
mean Φ	1.36				
k	4.00	3.00	3.00	3.00	3.00
Richness					
θ_T, θ_i	1.51	1.50	1.22	1.34	1.22
Φ_i		1.55	2.37	2.02	2.37
Mean Φ_i	**2.08**	(Jackknife value for Richness)			
Evenness					
θ_T, θ_i	5.32	3.08	4.64	3.91	4.64
Φ_i		12.01	7.35	9.54	7.35
Mean Φ_i	**9.06**	(Jackknife value for Evenness)			
STD Φ	1.64				
SE Φ	0.74				
Mean S_T	1.75	1	1.5	1.25	1.5

Table 35. Results of Jackknife analysis for richness and evenness of the MC2 lithic tool assemblage, McCulley Creek site, Unit G. Symbols and abbreviations follow Kaufmann (1998) and include: N = sample size; S_T = total number of analytical sets (i.e., S = species); S1, S2, S3, etc. = analytical sets; θ_T = the estimate of heterogeneity for each of the total assemblages (averaged from the individual estimates for heterogeneity for each analytical set (qi)); Fi = the pseudovalue for each analytical set; k = analytical groups included in each analytical set; STD F = standard deviation of pseudovalue mean; SE Φ = standard error of pseudovalue mean.

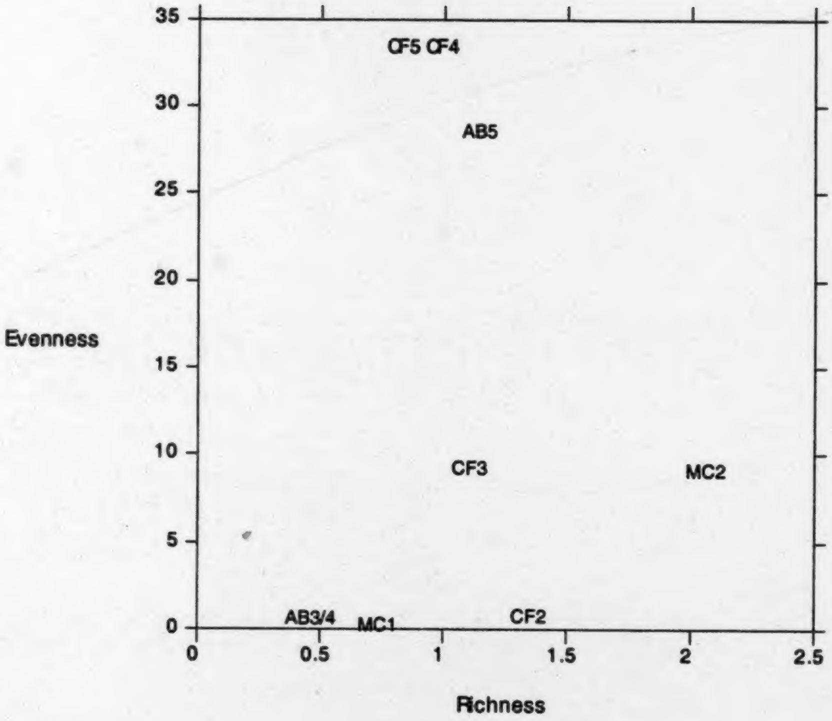

Figure 129. Cross-plot of richness and evenness indices for all assemblages.

early hunter-gatherer logistical and residential mobility in the LSRC relates to the larger cultural sphere of Plateau hunter-gatherer lifeways quite well.

Culture Change and the Oasis Effect: Correlation or Coincidence?

The fact that changes in lithic technology, residential, logistical, and subsistence strategies occur during a period of increased riparian stability and productivity should be apparent to the reader at this point. Despite the observation that both cultural and ecological changes appear to correspond at similar temporal scales, we must remember that simple correlations are not acceptable explanations. However, identifying the changing nature of the environmental circumstances of hunter-gatherers is an important part of the explanatory process in evolutionary archaeology. What was the potential role of changing environmental conditions in this process of cultural reorganization, if any? Stated more specifically, can the reasons for the changes in point styles, logistical organization, and subsistence patterns be related to different uses of, or interactions with, the changing riparian ecosystem of the canyon? And if so, how might these changes reflect the conditions and character of early social systems? Obviously, increasing productivity of canyon riparian zones would not go unnoticed by southern Plateau hunter-gatherer groups. Just as the geologic record suggests that the LSRC riparian ecosystem was more unstable prior to 9,000 yr BP or so, proxy records from the riparian zone show much more landform and vegetative stability after this time. Thus, we might expect archaeological patterns of canyon use before and after 9,000 yr BP to reflect this ecological change to some degree; that is, if hunter-gatherers chose to take advantage of rising riparian ecological productivity.

From the view of microeconomic theory, the potential decision-making systems employed by early hunter-gatherers of the LSRC during various early Holocene environmental contexts can be explored in regards to their rationality or cost-effectiveness, casting light on the functionality of different strategies. The problem with such an endeavor, however, lies in the quantitative requirements of such models. Attempting to establish search time estimates for diet breadth models might be futile in this study, based on the present lack of information regarding the operational energetics of hunting and gathering in a late Pleistocene to early Holocene-age canyon context.

Without having conducted a quantitative solution for microeconomic foraging models (which are summarized in Stephens and Krebs 1986, and Bettinger 1991) as a means of evaluating the economic reasons behind culture changes seen after 9,000 yr BP in the study area, certain basic statements can still be made by considering the parameters of such microeconomic models. For example, when handling time increases beyond searching time in foraging activities, the cost, or energetic expenditure, soon exceeds the benefits, or energetic yields, of the resource that is being sought. In the case of a late Pleistocene LSRC ecological context, as discussed in Chapter Six, the benefits of searching for, pursuing, and killing high-ranking game such as elk, deer, and mountain sheep in and immediately adjacent to the LSRC might produce greater economic benefits than attempting to intensively exploit various lower-ranking resources in the canyon riparian zone. These benefits might increased if the hunt was conducted at certain times of the year when the density and predictability of large game animals at their physical peak could be best exploited (e.g., during the fall and early winter rut). During the late winter and early spring months, the dispersion of large game animals into small groups across the landscape, while in a steady rate of declining health due to poor forage conditions, would be expected to increase searching time and lower the energetic yield of game.

Applying this line of economic reasoning to LSRC ecological models, the fact that the earliest assemblages in the study area appears as part of a collector-like logistical strategy makes sense. If the Cooper's Ferry site provided a staging point for Paleoarchaic hunters, then the creation of an equipment cache to facilitate this task would not be unexpected. The relatively low density of artifacts in LSRC Paleoarchaic occupation horizons seems to suggest that task-oriented large game hunters only used the canyon for short periods of time, perhaps subsisting on smaller, lower-ranked, low-density resources that were available in the canyon until the hunt was completed. The length of time Paleoarchaic hunters stayed at the Cooper's Ferry site was likely determined by the success or failure of the task at hand and not tied to the potentially low carrying capacity of the canyon itself.

As the alluvial riparian ecosystem of the LSRC began to flourish by ca. 9,000 yr BP, the increased floral and faunal productivity expected in both terrestrial and aquatic biomes likely altered the range of potential resources and their energetic returns. Changes in riparian and slope/upland portions of the LSRC and its adjacent areas appear asynchronous at this time, presenting both problems and opportunities.

Discussion in Chapter Six identified increased aridity and summer temperatures as likely having a detrimental effect on the lower-elevation ranges used by large ungulates, such as elk and sheep during the early Holocene. Xerification trends seen in the southern Plateau during the early Holocene are expected to force large ungulates, by and large, into higher elevation areas for the majority of the year. Thus, hunter-gatherers choosing to live in the canyon bottom possibly required special, dedicated trips to hunt elk and mountain sheep, as these animals were not likely to be encountered regularly or reliably below the canyon rim. Grayson and Cannon (1999:149) offer some economic predictions as to how hunter-gatherers might respond to these new ecological conditions:

> Resource depression models predict that lower-ranked resources will be incorporated into the diet as encounter rates with higher-ranked resources decrease, and that diet breadth may expand as a result. However, applications of these models do not require a measure of diet breadth, or the "total number of resources in the diet" (Kaplan and Hill 1992:171); they simply require showing that encounters with high-ranked resources declined through time.

To provide an independent evaluation of the mechanisms behind the resource depression, Grayson and Cannon (1999:149) advise that, "...it is essential that resource depression hypotheses be tested using data unrelated to the efficiency index itself." An example of a suitable test could be an evaluation of the habitat condition and quality of the mammal species that shows a reduction in use among archaeological assemblages.

While the economic benefits of a decision to shift towards the lower-yield, higher-density, and more predictable resources of the riparian zone may be borne out through quantitative microeconomic analyses it is arguable that the modeled habitat conditions for higher-ranking game satisfies Grayson and Cannon's (1999) requirement that a decline in these resources can be shown to help explain economic shifts toward lower-ranking resources. The social conditions that LSRC hunter-gatherers lived under must also be considered, as changes in economic behavior can produce wider effects on sociocultural systems. What remains, then, is to incorporate the contextual basis of economic and social behavior within a Darwinian evolutionary framework to generate potential explanations for culture change.

Towards an Interpretation of Early Plateau Culture Change

Having shown that early Holocene changes in LSRC hunter-gatherer mobility and logistical strategy, revealed in lithic tool assemblage structure and settlement patterns, matches regional patterns of early Holocene foraging strategies, it is time to turn our attention to the development of interpretations for the Paleoarchaic-Archaic transition. Because the archaeological evidence of the LSRC relates to regional records of early cultural change, the interpretations presented here are widely applicable to southern Plateau prehistory. In the sections to follow, discussion will draw upon the theoretical concepts of cultural transmission presented in the beginning of this chapter.

Perhaps the "very productive places" that Ames (1988) mentions as crucial to promoting social aggregations among early Plateau hunter-gatherers were also present in biotically-flourishing riparian zones in various areas of the region. These riparian zones potentially appeared where the parameters of a fluvial system provided adequate water for phreatophytic plants and where nutrient storage during retarded carbon cycling enhanced aquatic ecosystems, which is modeled in the LSRC during the early and middle Holocene. Enhanced erosional inputs following xeric plant expansion on slopes, increased sediment inputs to rivers, and reduced fluvial discharge during the early and middle Holocene periods, likely promoted the aggredation of alluvial floodplains in other Plateau river canyons. Whether these alluvial systems supported high proportions of mesic C_3 plants seen in the LSRC riparian zone through most of the Holocene cannot be determined with the data at hand. Indirect evidence, however, may be available in the settlement patterns of early hunter-gatherers. For example, it is likely that the main attraction of sites like Marmes Rockshelter and Windust Caves was not due to the promise of a bedrock roof over one's head. Instead, both of these sites are only a short distance from major waterways, which had early floodplain development (Hammatt 1976). Thus, the use of rockshelters by early Holocene hunter-gatherers may only be circumstantial, and, more importantly, related to an intensive exploitation of highly productive riparian ecosystems. Arguably, the onset of the "oasis effect" in early Holocene river canyons of the Plateau provided different opportunities for hunter-gatherers. How this situation was possibly met by early peoples, and the unintended consequences of their choices, are presented below in two scenarios.

Scenario One

Prior to ca. 9,000 yr BP, Plateau environments, including alluvial riparian contexts, were subject to highly-variable climatic conditions and geomorphic responses at relatively short time scales. This variability can be traced to the greater seasonal extremes in solar insolation projected at 21,000 year cycles of Earth-Sun geometry (see Kutzbach 1987), the post-glacial readjustment of hydrological systems (Hammatt 1976; Knox 1983) and the operation of larger atmospheric-oceanic processes that produced periods of climatic instability in the Northern Hemisphere at the LP-EH transition (e.g., Ruddiman 1987; Alley et al. 1993; Mayewski et al. 1993; Taylor et al. 1993). Because of this heightened short-term environmental instability, it is expected that low populations of early hunter-gatherers were widely distributed across the Plateau in small highly-mobile groups, exploiting a resource base marked by high variability and low reliability (Ames 1988). Because of the particular conditions in this environmental context, cultural transmission in early hunter-gatherer groups is expected to operate under a mode of guided variation before ca. 9,000 yr BP.

To elucidate the operation and applicability of cultural transmission theory here, some examples are needed. Under a process of guided variation, a young hunter-gatherer would observe the total range of diversity in projectile point manufacture available to him and choose to emulate the mean of observed behaviors. Once deciding on what process and form to follow in the manufacture of points, our individual tests these behaviors through trial and error, in order to best fine-tune the process relative to various functional requirements (e.g., the performance requirements of a tool in relation to its use in hunting elk). Because our exemplary hunter-gatherer makes adjustments through trial and error, guided variation will produce greater diversity in replicated behavioral patterns through time. The use of guided variation under circumstances of high environmental instability at short time scales relates to the hunter-gatherer's desire to reduce risk by adopting a strategy that is best suited (i.e., allows a minimum-level of economic return when used) for the specific environmental and social situations at hand. Since late Pleistocene to early Holocene southern Plateau canyon environments are expected to be very diverse from area to area, hunting strategies that may work in the LSRC may be unsuitable for conditions present in the nearby Lower Snake River Canyon. Therefore, the greater diversity among Windust projectile point forms in the southern Plateau region, for example, may reflect the operation of a cultural transmission process such as guided variation within scattered, small-density hunter-gatherer populations dealing with a highly diverse, and relatively unreliable set of environmental and resource conditions.

Scenario Two

Stability and increased productivity in riparian ecosystems after ca. 9,000 yr BP brought about a rise in riparian biotic productivity and allowed for increased population aggregation in the LSRC (and, assumedly, in other similar riparian contexts throughout the Plateau), although not likely on a permanent basis. Hunter-gatherer groups were potentially able to stay in one place longer and congregate in higher numbers in the context of a more productive riparian ecosystem. This situation is in contrast with the lowered reliability and productivity hypothesized for subsistence resources on canyon slope and adjacent plateau prairies. Thus, riparian zones appear to have offered hunter-gatherers a context containing important opportunities. In response to the appearance of these riparian "oases", hunter-gatherer groups appear to change patterns of residence mobility and increase population aggregation in the LSRC, potentially imparting unintended consequences for the way in which cultural behaviors were replicated through time. By choosing to exploit riparian environments more intensively, different social transmission mechanisms (i.e., unlike the process of guided variation, the adoption and use of behavioral traits will occur without independent testing and modification) might be emphasized by hunter-gatherers of the LSRC, including the process of frequency-dependent adoption.

Returning again to our hypothetical hunter-gatherer, we can see how new opportunities provided under conditions of increased riparian productivity could affect patterns of cultural transmission. Because flourishing riparian environments probably offered a greater degree of predictability for the location and productivity of subsistence resources than in the surrounding, increasingly drier upland landscape (i.e., producing an "oasis effect"), there may have been greater social pressure to adopt those cultural behaviors that were most effective in riparian zones, such as certain projectile point manufacture strategies, without incurring the costs (and risks) of trial and error. Bettinger and Eerkens (1997:179) state that, "...emphasis on social transmission will be directly proportional to the cost of trial and error, and inversely proportional to the fitness differences between alternative behaviors and social transmission costs." Under a frequency-dependent bias mechanism, our hunter-gatherer would, "survey the local model pool, then adopt the most common behavioral variants in preference to less common alternatives" (Bettinger and Eerkens 1997:179; Boyd and Richerson 1985). As a result, populations of behavioral traits (e.g., projectile point manufacture techniques) become more heterogeneous and variation is reduced.

The interpretation that hunter-gatherers began to use the increased resource productivity and predictability of riparian zones more intensively after 9,000 yr BP, as environmental conditions outside of the canyon bottoms were becoming less productive and predictable, is intended to emphasize the role of individual decision-making in prehistory. I argue that changes in culture came about as a result of the choices hunter-gatherers made to exploit the *opportunities* that early Holocene riparian zones provided. Thus, we must see the prehistory of the LSRC as reflecting the choices made to contextual problems, and not misinterpreted as a deterministic forcing of a certain response to environmental changes. While the increased xerification of canyon slopes and adjacent uplands potentially limited the range of choices prehistoric peoples had to make a living--forming the basis for a deterministic explanation that peoples were somehow "forced into" a pattern of increased riparian use--it is equally arguable that hunter-gatherers could also choose to continue to employ earlier Windust patterns of low population density and strategic collector-like exploitation of key resources where and when they were most available. Instead, the archaeological evidence of the LSRC suggests that hunter-gatherers chose to exploit lower-yield, higher-density, and more reliable resources of canyon riparian zones instead of specializing in large upland game; all of which reflect patterns of prehistoric decision-making. These patterns suggest that priorities were placed on achieving a minimum level of economic benefit (in contrast to maximizing returns) while improving on the reproductive success of their population by providing ways to increase population aggregation and social interaction. The difference between cultural patterns from the pre- and post-9,000 yr

BP periods, then, might be said to be partially based on the differences in economic choices made to exploit opportunities in their respective environmental contexts, and partially caused by the sociocultural consequences associated with those choices.

Projectile Point Frequencies and the Style-Function Dichotomy

While it may be easier to argue that the changes in economic and organizational patterns reflected in Paleoarchaic-Archaic assemblages are related to functional aspects of human behavior, determining the role that other changes in the archaeological record played may prove more difficult. In the case of changing early projectile point styles, the source of this difficulty is tied to the long-standing debate about style and function in cultural behavior. Although some in the neo-Darwinian corner argue that the traditional style-function dichotomy--i.e., some traits are functional and therefore subject to selective forces, while other traits are stylistic and useful only as temporal and spatial markers of social expression since they are neutral to selection--should be maintained (e.g., Dunnell 1978, 1980), others point out how these classificatory boundaries are less rigid than originally thought (Bettinger et al. 1996). Furthermore, cultural transmission theory (Boyd and Richerson 1985) offers productive avenues for investigating how changing point styles might relate to functional aspects of cultural behavior. To illustrate how considering different issues of style and function can produce different interpretations of the same archaeological phenomena, I will present three different explanations for the change from stemmed to leaf-shaped lanceolate projectile point forms across the Paleoarchaic-Archaic transition. Coinciding with the adoption of new organizational patterns, leaf-shaped points, which are present in Windust assemblages in small percentages (e.g., H.S. Rice 1965; D.G. 1972; Sanders 1982), are manufactured in increasingly larger quantities through time than stemmed varieties. Why this occurred is not adequately investigated, however, and provides a ready topic for which the function-style dichotomy problem may be investigated in evolutionary terms. To address the problem of the shift from stemmed to lanceolate points, explanations will be generated that are based on different processes of stylistic evolution as outlined by Bettinger et al. 1996, which include: 1) nonselective random processes; 2) ordinary adaptive forces; 3) patterning by correlation among characters.

Nonselective Random Processes

The view that projectile point styles represent nonfunctional traits and are therefore subject to random patterning through time can be supported through a consideration of the changing frequencies of point styles across the Paleoarchaic-Archaic transition. Bettinger et al. (1996:144) outline how this process should work:

> If individuals acquire stylistic traits by faithfully copying others, and then make innovations that are random with respect to adaptation, the resulting patterns may be random in the sense that there is no correlation between stylistic features and environmental variables affecting fitness.

In regards to the production of projectile point styles, this process of replication and modification, when multiplied across many generations, might be expected to produce a pattern of rising and falling frequencies of individual forms, much as a seriation curve might reflect. Figure 109 shows the changing frequencies of projectile point styles at Cooper's Ferry in the form of a seriation plot (cf. H.S. Rice 1965). This figure illustrates that the replacement of stemmed point styles by lanceolate and notched styles occurs gradually, over a span of thousands of years. At a human scale of time, this corresponds to the passing of many generations, each of which is given the opportunity to ever-so-slightly alter the replication of projectile points through small modifications. The sum of these modifications could plausibly account for the frequency changes in stemmed and lanceolate point styles in the LSRC.

This explanation supports a non-functional role for projectile point forms, equating them to a selectively-neutral trait that follows a stochastic frequency pattern through time. Accepting this process as an explanation for the shift from Windust stemmed to Cascade lanceolate points requires adherance to a mode of cultural transmission that involves selection and modification of traits through individual experimentation during replication, such as frequency-dependent bias. Should we expect that a stochastic shift from stemmed to lanceolate points would occur at a regional scale? In the case of the southern

Plateau, it was discussed earlier that the shift in frequency from Windust to Cascade point styles appears to be a widespread archaeological phenomena. If changes in point style were truly stochastic, such regularity stylistic frequency might not be expected to follow such a synchronized pattern of replacement.

Ordinary Adaptive Forces

Under this theme, we might look to the functional advantage that a change to producing and using leaf-shaped lanceolate points might offer its bearer after 9,000 yr BP. There are many directions this argument can proceed. The functional superiority of Cascade points compared to stemmed points in post-9,000 yr BP toolkits might be tested by conducting materials and engineering studies of point forms, or replication experiments that relate to issues of portability, replacement, durability, and so on. As part of this effort, we must also show how the inclusive technological traits associated with lanceolate points could provide their bearer with an adaptive advantage under certain selective conditions.

If post 9,000 yr BP LSRC hunter-gatherers chose to exploit riparian ecosystems more intensively during a period of increasing regional xerification by implementing a foraging logistical strategy with a relatively low degree of residential mobility, selective pressures might favor the operation of social transmission mechanisms that produce changes within projectile point styles relating to new problems. One argument in this theme might address changes in the functional role of stemmed points through time. If the production and use of stemmed points was tied to the task-oriented upland game strategy seen before 9,000 yr BP, and if upland game hunting was somewhat de-emphasized after 9,000 yr BP, their use and production was probably less important and eventually dropped out of toolkits to be replaced by leaf-shaped points (which, again, were already present in the Paleoarchaic toolkit).

Changes in the availability of different toolstones, either as an unintended result of changes in settlement patterns or shifting ecological conditions, possibly caused LSRC hunter-gatherers to emphasize different projectile point technologies after 9,000 yr BP. Increased reliance on igneous toolstones for projectile point manufacture is argued to be a characteristic of the Cascade Phase in the southern Plateau (e.g., Leonhardy and Rice 1970; Bense 1972). The relative frequency of lithic materials that Cascade points were made from, however, can be considered as a indicator of the availability of different materials, either as an end-result of cultural strategies, toolstone availability, or both. Thus, the shift towards the production of leaf-shaped points instead of stemmed varieties after 9,000 yr BP may reflect a desire among hunter-gatherers to maintain a reduced mobility settlement strategy emphasizing riparian habitats while faced with the difficulty of working the more abundant igneous and metamorphic toolstone materials, as constrained, in part, by an aggrading alluvial environment.

If post 9,000 yr BP hunter-gatherers chose to exploit riparian ecosystems during a period of increasing regional xerification by implementing a foraging logistical strategy that included a relatively low degree of residential mobility (compared to earlier patterns), then we might expect to see changes within projectile point styles as an inclusive aspect of the consequences of emphasizing riparian resources. Put another way, in choosing to making a living, for at least part of the year, by exploiting the particular conditions of the LSRC riparian zone, hunter-gatherers could find that it was difficult to continue to manufacture and replace stemmed points from the igneous toolstones that were most available, in contrast to the relative ease of producing basalt and andesite leaf-shaped points. Additionally, since cherty toolstones were more difficult to find, continuing to produce points from chert had an added cost embedded in material procurement. In response to this problem, leaf-shaped points are manufactured in increasingly larger quantities through time than stemmed varieties. From an evolutionary perspective, it can be argued that individuals using knapping strategies that emphasized the manufacture of point styles from more available igneous toolstones might enjoy a reproductive benefit over those that continued to make stemmed points under these conditions.

On this basis, we could argue that those hunter-gatherers (call them Group A) who began using igneous toolstones rather that expend additional time and energy to search for, collect, and transport cherts from various points in the landscape, had selective benefits bestowed upon them at the expense of neighbors (Group B) that employed other lithic procurement strategies. The end-effect of this increased efficiency in point production could allow Group A to be able to secure suitable subsistence base for larger populations (as more people were able to forage more often), having not bothered to obtain the increasingly scarce cherts, possess higher rates of biological and cultural reproduction than Group B. Since the source of cherty toolstones was likely "cut off" in the riparian zone after 9,000 yr BP as fine alluvial sediments filled the canyon bottom, arguments for lithic procurement being "imbedded" (*sensu* Binford 1980) in other foraging activities is rejected: in this aggrading alluvial context, hunter-gatherers were often required to make special trips to acquire suitable cherty lithic materials. Since our early Holocene hunter-gatherers likely spent part of the year away from the riparian zone, cherts could be obtained during these times, which would help to explain the persistence (albeit at a much reduced level) of non-igneous toolstones after 9,000 yr BP.

Changes in the frequency of projectile point styles is a common means of defining the Paleoarchaic-Archaic transition in the Plateau, as Windust stemmed styles gave way to Cascade lanceolate forms. It is possible that the emphasis on leaf-shaped lanceolate projectile point manufacture over stemmed varieties after 9,000 yr BP can be explained, in part, as related to the choices made by hunter-gatherers to reduce their residential mobility within the environmental parameters in southern Plateau canyons. This theme is visited by Andrefsky (1995) and Reid (1997), who argue opposite sides of an issue addressing the availability of toolstone materials in the Snake River Canyon and its affects on Cascade economic and settlement patterns.

Andrefsky maintains that cherty toolstones are nearly absent from alluvial gravels in the Snake River Canyon, and the apparent reliance on this lithic material--as seen in Cascade assemblages--points to a pattern of high logistical mobility, and argues against a "riverine orientation." Reid (1997) observes that cherty toolstones can be found as primary deposits interbedded between basalt flows, and need not only be seen as components of alluvial gravels. The distribution and quality of interbedded cherts is neither constant nor predictable in a igneous bedrock canyon, however, due to the various processes that contribute to chert formation (Luedtke 1992). The presence of cherts in alluvial gravels, while also randomly distributed within these deposits, can be considered to occur in a more spatially-restricted, or "concentrated" (i.e., in terraces and bars along the river) context in the landscape, as compared to the distribution of primary chert deposits found interbedded in canyon bedrock. Early Holocene to middle Holocene alluviation in the LSRC and Lower Snake River Canyon during formation of early floodplain deposits (Davis n.d.; Hammatt 1976) possibly restricted access to chert cobbles by burying alluvial gravels beneath fine-grained sediments. Because cherts are relatively concentrated in alluvial gravels, as compared to the surrounding landscape, limiting or removing access to alluvial gravels during periods of floodplain growth would be expected to lower the overall availability of cherts for knapping.

Increased reliance on igneous toolstones for lithic tool manufacture is stated as a characteristic of the Cascade Phase in the southern Plateau (e.g., Leonhardy and Rice 1970; Bense 1972). In the LSRC, Cascade points were predominantly made from cherty toolstones. Of the 17 leaf-shaped lanceolates (both complete and fragmentary) found in early and middle Holocene components, however, only one was made from an igneous material; the remaining 16 were manufactured from microcrystalline silicate materials. At the Cooper's Ferry site, igneous and metamorphic materials comprise 4.9% of debitage pieces recovered from the Windust component that immediately precedes the onset of increased riparian ecosystemic productivity. Cascade assemblages associated with this ecological change show a reduction in use of igneous (now 1.5% of total debitage recovered, by count), tuff (0.2% by count), and metamorphic rocks (0.2% by count). Non-chert toolstones share a larger proportion of the debitage population when weight is considered, with igneous and metamorphic rocks making up 13.2% of the Windust debitage assemblage, and 24.2% of the Cascade assemblage at Cooper's Ferry. At the American Bar site, igneous rock makes up 1.6% of the Cascade debitage by weight and 1.6% by count. These observations appear to support Andrefsky's (1995) statement that Cascade peoples did not emphasize non-cherty toolstones, at least in the LSRC sites investigated. The role of igneous and metamorphic materials in manufacturing expedient tools appears to be supported by considering their relative proportion by weight; however it does not necessarily lend strength to his additional views on how this expediency relates to residential mobility. The slight differences in the use of lithic toolstone types between LSRC Windust and Cascade assemblages offers little support for the view that igneous materials are used in greater frequency after 9,000 yr BP.

Cherts and other glassy lithic materials are found in various locations throughout the LSRC, formed either through contact metamorphism as lava came in contact with a high-silica deposit (e.g., sand or tephra), or through chemical precipitation of chert in bedrock voids (producing materials commonly termed opal, chalcedony, or red jasper). As well, the presence of a distinctive green-hued, high-quality cryptocrystalline silicate, which is locally named Salmon River Greenstone, is thought to be derived from marine deposits associated with the Seven Devils Formation. High quality igneous toolstones appear in alluvial fans, colluvial aprons, and as canyon rimrock, as evidenced by the presence of basalt quarrying sites throughout the southern Plateau (e.g., Womack 1977; Dickerson 1998). Extremely fine-grained metavolcanic bedrock deposits of the Wild Sheep Formation (Gaston and Bennett 1979) were worked at the McCulley Creek site, where the bedrock type is widespread. Although alluvial aggradation might obscure the location of cherty toolstone clasts in the riparian zone, hunter-gatherers could still acquire high-quality siliceous toolstone from various points in the canyon. In this situation, a rise in the use of non-cherty toolstones, such as basalts, andesites, and metavolcanic lithologies might be seen in debitage and tool assemblages. However, due to the local availability of cherts in primary deposits, and that opportunities to collect cherty materials were provided during trips to outside of the canyon, a significant shift in use of igneous toolstones is not expected, except where suitable high-quality igneous or metamorphic toolstone is found in proximity to a camp or activity station (e.g., as seen at the McCulley Creek site) that would satisfy "situational" tool production needs (Andrefsky 1995). Therefore, Andrefsky's (1995:95) interpretation that, "Cascade phase populations were highly mobile and visited major river drainages during only part of an annual cycle", which strongly depends on an assumption that cherts were absent in early Holocene canyons, is rejected on similar grounds as Reid (1997) presented, as it fails to account for the particular geologic context of toolstone sources in the LSRC. Equally so, establishing a functional explanation for the shift away from stemmed point production on the basis of toolstone frequency is not supported by the data at hand.

Patterning by Correlation Among Characters

The change in point styles may proximally relate to other innovations or adoptions in weapons technology after 9,000 yr BP, which may or may not be related to changes in other parts of the hunter-gatherer organizational strategy. For example, one might seek to evaluate how the transition from larger stemmed points to smaller lanceolate points might relate to the development of atlatl technology from functional and stylistic grounds. For whatever reasons, unstemmed lanceolates might perform better in an atlatl weapons system. Alternatively, if the use of a certain point style--say leaf-shaped lanceolates--was packaged along with the atlatl weapons system, the transmission of this technology could take the form of frequency-dependent bias where behaviors and associated traits are adopted in their entirety. Bettinger et al. (1996:152) address this very issue:

> For example, a complex tool with many parts may be learned more or less as a whole, so that its individual components will seldom "recombine." An adaptive innovation in one part of a tool may cause the hitchhiking of nonadaptive variation and stylistic features with regards to other parts.

In this case, the increased frequency of Cascade points after 9,000 yr BP is not related to their functional role, which could be stylistically neutral in this case, but to their association with an innovative technological system with broad appeal. The idea that a certain style of projectile was packaged together with the technological concept of the atlatl weapon system could help explain the rapid spread of Cascade points in the Pacific Northwest, and provides a different explanation for the broad distribution of leaf-shaped lanceolate points throughout western North America during the early Holocene (cf., Butler 1961; Daugherty 1962; Warren 1967). Although atlatls are yet to be found older than 8,000 yr BP in North American sites, the presence of spurs and foreshaft parts in Paleoindian-age sites across beyond the Pacific Northwest is suggestive of the antiquity of this technology (Dixon 1999). The uncertainty of when this technology arrived in the Plateau is reflected in Ames et al. (1998:104) statement that stemmed and lanceolate points of late Pleistocene to early Holocene age were "probably" associated with atlatl weapons systems. Perhaps a greater question is why the atlatl did not enter and spread throughout the Plateau until after 9,000 yr BP if possibly present much earlier in other North American regions. Although technological studies of hafting techniques (Thomas 1978; Bryan 1980; Musil 1988), breakage patterns (Hutchings 1997, 1998), and projectile design (Thomas 1978) may provide cogent argume[illegible]or the operation of certain point forms as part of an Plateau atlatl weapons system in the absence of evidence for atlatls themselves, discovering an atlatl or parts clearly thereof in a proven pre-9,000 yr BP context would be the most convincing evidence.

Other Considerations

All of this discussion dealing with the functional efficiency and inherent risk in strategies of projectile point manufacture hinge upon the assumption that lithic tools were of primary importance to LSRC hunter-gatherers. It is also possible that problems facing early hunter-gatherers were met by innovation in or increased reliance on organic tool technologies, such as traps, snares, nets, weirs, bone and antler spears, leisters, harpoons, and clubs; all of which are not typically preserved in open sites. This could produce a tangible effect on the role of lithic projectile points, which could be difficult to fully evaluate. Evidence that leaf-shaped Cascade lanceolates were used as projectile points comes from an unusual observation made from the Kennewick Man (or Ancient One) skeletal remains. The discovery of a leaf-shaped lanceolate, identified as a Cascade point, imbedded in the pelvis attests to the fact that such artifacts were indeed part of a weapon system (Fagan 1999); however, because of their sharp edges, Cascade lithic projectile points could also act in a multipurpose role as part of a foraging toolkit. Bifaces, including those classified as projectile points, can be used for a variety of tasks, however, including cutting, scraping, sawing (Stevens and Galm 1991; Beck and Jones 1993). If used in conjunction with various organic tools, which assumed the role of certain lithic tools in Windust assemblages, Cascade points were possibly used in a more general multipurpose manner. Because projectile points possibly had new functions in a foraging strategy with an increased reliance on organic tools, perhaps stemmed forms used previously became less suitable than leaf-shaped lanceolate points. Hypothetical aspects of this suitability issue might include the following: (1) Cascade points were producted more efficiently (i.e., less material waste) than stemmed forms, allowing for the conservation of lithic material, which was beneficial in a reduced mobility settlement pattern; (2) because of their simpler form, lanceolate points were easier to make from igneous and metamorphic toolstones; (3) repair of broken lanceolate points--particularly where the blade portion is snapped off at the haft--might require fewer steps with greater chances of success than with stemmed forms.

In order to evaluate the strength of these three hypotheses, and to ultimately test whether functional differences exist among stemmed and lanceolate points and their production, future tests must be made. To my knowledge, no use-wear studies are available on Cascade projectile points, which could determine if they were employed for other tasks. Therefore, it is difficult to say whether the shift from

Windust stemmed to Cascade lanceolate points represents a functional reorganization of formal tool classes as part of the observed logistical and settlement changes. Detailed debitage analyses should be made to compare Windust and Cascade reduction strategies in order to explore whether any differences observed between the two phases can be related to the various issues raised here.

A Riverine or Riparian Orientation?

The LSRC data support a view that riparian resources were productive enough after 9,000 yr BP to enable Cascade peoples to exploit the canyon bottoms more intensively than during the previous Windust phase. Measures of assemblage structure conducted on LSRC assemblages suggest that Cascade peoples employed a foraging logistical strategy, as also determined by Ames (1988) and supported by Andrefsky (1995); however, these two authors de-emphasize the importance of river canyons for Cascade peoples. Ames (1988:335-336) appears to consider fishing, and only in prime locations, as the main benefit of Plateau river canyons during the early Holocene. Andrefsky (1995:108) maintains that Cascade peoples, "scheduled their visits to the Snake River and other major waterways of the southern Plateau to procure one or two resources that they knew would be seasonally available, and that they may have traveled from a distant location." While sharing their view that Cascade peoples likely employed a foraging strategy, which included residential movement, it appears that particular aspects of the LSRC data reflect a slightly different lifeway. First, evidence suggests that Cascade hunter-gatherers used canyon environments much more intensively than their Windust predecesors, based on the relative density of cultural and faunal materials found in Cascade components and the presence of occupational features, such as hearths and roasting pits (e.g., Davis and Schweger n.d.:Figure 99). This difference in intensity of canyon use is thought to result as greater numbers of Cascade peoples used locations like the Cooper's Ferry site repetitively and stayed longer, exploiting various animals and plants from the surrounding riparian zone and tributary canyons. Hypothetically, such a scenario might work this way: individuals or small groups (of perhaps 2 to 3 persons) foraged outward from a central base camp, exploiting a relatively small area (e.g., 15 to 20 km^2) within the canyon corridor for a short amount of time (e.g., one to three weeks, depending on the resources available); after a particular time (determined by a day's success or lack of success) our foragers would return to camp to process, cook, and share aquired foods, disseminate information on hunting and gathering conditions, and repair or replace tools, creating a relatively dense archaeological signature; after animal and plant resources were sufficiently exploited within a certain range, the camp was disbanded and our hunter-gatherers moved to another productive locale along the river. The cyclic occurrence of these residential and economic activities would be expected to create the archaeological record observed in LSRC assemblages post-dating ca. 9,000 yr BP, similar to Bense's (1972:105) description of Cascade occupations:

> At each location a variety of activities were performed: butchering, cooking, fishing, food and hide processing, tool manufacture, and general residence. At each site consistency through time of these activities is indicated by thick uniform cultural deposits and large numbers of similar artifact types. The people regularly reoccupied the settlements for similar purposes.

Upland localities were used to extract specific resources when and where they were most productive (e.g., elk hunting during mating season or berry harvesting), in the same manner argued by Galm et al. (1981). While large amounts of food could be procured during these collector-like expeditions, formal storage facilities were apparently used infrequently, if at all; however, the lack of evidence for storage pits and food caches may be an artifact of our archaeological sample size. Thus, Cascade peoples might live much of the year within river canyons, choosing to maintain a "tethered" relationship with productive riparian ecosystems (cf. Willig 1984, 1988). Because seasonality studies were not conducted here, it is difficult to establish how long Cascade peoples lived along the Lower Salmon River each year.

Regarding the role of fishing, paleoecological modeling (Davis n.d.) casts doubt on the productivity of anadromous fish resources. Lower Salmon River Canyon salmon runs were likely too unproductive and unreliable during the LP-MH to act as an important subsistence resource. While the occasional anadromous fish was undoubtedly taken, intensive salmon processing sites are not expected in the study area until after 2,000 yr BP, following a period of major alluvial downcutting and hydrological change (Davis n.d.). Recovery of non-salmonid remains from early components in sites along the Salmon River may point to additional pressures provided by fishes that predate on young salmon (e.g., northern pikeminnow and whitefish). Thusfar, clear evidence of the importance of salmon fishing, as seen in faunal remains, fishing gear, and housepit structures, is found only in LSRC site components dating younger than 2,000 yr BP (Butler 1962, 1968; Davis, unpublished data). Considering these aspects, viewing hunter-gatherer occupation in the LSRC as representing a "riverine orientation" misses the mark, given the loosely-implied role of fishing in such a lifeway. Instead, Cascade peoples might be thought of as having a *riparian orientation*--involving the intensive use of highly productive ecotone that lacks a modern equivalent in the canyons of the southern Plateau--which, until now, is poorly illuminated by archaeological research.

Conclusions

While many lines of inquiry that would help to evaluate the hypotheses presented here are not addressed in this study, the discovery that early Holocene riparian environments of the southern Plateau potentially offered a highly productive ecological niche for hunter-gatherers is an important first step. This study attempted to apply neo-Darwinian evolutionary theory to explain changes in material culture at the Paleoarchaic-Archaic transition by considering the effects of changing modes of cultural transmission within the context of evolving riparian ecosystems. In an effort to avoid the pitfalls of determinism, an emphasis was placed on the role of individual decision-making, and how opportunities present in early Holocene river canyons were possibly exploited by hunter-gatherers. This writer maintains that under an evolutionary perspective, the environmental context of the LP-EH of the southern Plateau should be viewed as a source of selective pressure. However, because humans make decisions about how to interact with and manipulate their environmental and social context, the archaeological record must be viewed as reflecting the consequences of these different choices, as played out through time. As archaeologists, we should also be sensitive to the potential that archaeological sites might hold evidence of several different solutions to problems provided by the same context, and that the prehistory of one canyon might not exactly match another--indeed this situation is expected where hunter-gatherers make use of different ecological niches.

Just such a situation was likely in operation prior to 9,000 yr BP, as hunter-gatherers extracted their living within unstable, rapidly changing environmental conditions. The stabilization of alluvial floodplain zones in the southern Plateau probably offered a highly productive ecosystemic niche, which was exploited through the adoption of different logistical, settlement, and foraging behaviors focused along the river corridor.

Admittedly, the reductionist stance of this study, with its lack of emphasis on the upland component of Plateau landscapes, may miss important ecological changes that occurred outside of the canyon during the early Holocene. Because of this position, it is difficult to fully evaluate whether riparian ecosystems were as important as hypothesized here. Future investigations of upland locales and sites will hopefully address this topic. Despite these problems, we must continue to address archaeological problems in the Plateau from a standpoint that integrates ecological perspectives at ever-increasing scales of resolution. Only by doing so can we hope to reveal the nature of past human-environmental relationships recorded in the static archaeological record.

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APPENDIX A. RADIOCARBON DATES

Clarification of headings shown in the table below are as follows: Site/Section refers to locality from which sample was collected; Provenience includes the stratigraphic position of the sample; Method denotes accelerator mass spectrometry (AMS) or standard ^{14}C counting method (Radiometric); TO = Isotrace Laboratory at the University of Toronto, Beta = Beta Analytic Inc., and Tx = University of Texas Austin under Lab Number heading; Material refers to the sample matrix--the difference betweeen wood charcoal and charred wood is related to the amount of combusted carbon in sample, mussel shell = calcium carbonate; Uncal. ^{14}C age presents radiocarbon ages of samples in uncorrected ^{14}C years before present (BP) with one-sigma standard error.

Site/Section	Provenience	Method	Lab Number	Material	Uncal. ^{14}C age
10IH1312	A/4	AMS	TO-7355	wood charcoal	modern
HC Trench 2	238 cm bs	AMS	TO-7813	wood charcoal	90 ±50
10IH1308	B/1308-555, L2	Radiometric	Beta-147093	wood charcoal	300 ±70
10IH1308	B/1308-1483, L9	Radiometric	Beta-147095	wood charcoal	320 ±50
10IH1308	B/1308-832, L4	Radiometric	Beta-147094	wood charcoal	460 ±70
10IH1312	B/3	AMS	TO-7350	wood charcoal	1,140 ±60
10IH395	395/12,Q/NW/L3	Radiometric	Tx-???	wood charcoal	1,370 ±40
10IH1312	A/3	AMS	TO-7354	wood charcoal	1,680 ±60
10IH1160	1160/F-L6	AMS	Beta-135613	wood charcoal	1,690 ±70
HC Trench 2	93 cm bs	AMS	TO-7812	wood charcoal	1,770 ±110
10IH1312	B/4	AMS	TO-7356	wood charcoal	1,780 ±50
10IH2491	2491/D1,D,L4	AMS	Beta-114808	wood charcoal	1,960 ±40
10IH2491	2491/67,D,L7	AMS	Beta-114805	wood charcoal	2,010 ±40
10IH2491	2491/50,D,L2	AMS	Beta-114804	wood charcoal	2,052 ±40
10IH1160	1160/CF1-132cm	AMS	Beta-135612	wood charcoal	2,320 ±90
10IH1220	A/7	AMS	TO-7353	charred wood	3,070 ±50
10IH1308	1308/32, 1, L5	Radiometric	Tx-9271	mussel shell	3,340 ±60
10IH1312	A/7	AMS	TO-7810	mussel shell	3,610 ±60
10IH1308	1308/231, 2, L9	Radiometric	Tx-9272	mussel shell	3,690 ±50
10IH1308	1308/79, 1, L9	Radiometric	Tx-9273	mussel shell	3,840 ±50
10IH1312	A, L10	AMS	TO-7811	mussel shell	3,930 ±60
10IH1308	1308/280, 2, L13	Radiometric	Tx-9275	mussel shell	4,940 ±60
10IH1308	1308/363, 2,10	AMS	Beta-11657	bone collagen	4,780±100
SR-35A	90-100 cm bs	AMS	TO-7820	soil humate	5,670 ±80
SR-23	100-110 cm	AMS	TO-7816	soil humate	6,040 ±620
SR-14	Strat. Unit 5	Radiometric	Tx-9138	soil humate	6,070 ±60
10IH1308	1308/237, 2, L10	Radiometric	Tx-9274	mussel shell	6,110 ±70
10IH1160	G/L18/194-210cm	AMS	Beta-142165	wood charcoal	6,250 ±70
10IH2491	2491/50,D,L13	AMS	Beta-114806	wood charcoal	6,780 ±50
10IH73	A/SE/410.98 masl	AMS	Beta-114948	wood charcoal.	7,300 ±70
10IH1220	250-260 cm	AMS	TO-7815	soil humate	8,030 ±310
10IH395	395/28, B, L10	Radiometric	Tx-9269	mussel shell	8,360 ±80
SR-35A	200-210 cm bs	AMS	TO-7821	soil humate	8,410 ±650
10IH73	73/279, A, L7	AMS	Beta-114952	wood charcoal	8,430 ±70
10IH73	RC4, A, L14	AMS	Beta-114951	wood charcoal	8,410 ±70

10IH73	SE/27	AMS	TO-7346	charred wood	8,710 ±120
10IH1160	G/L18/205-206cm	AMS	Beta-142166	charred wood	8,760 ±70
10IH1220	190-200 cm	AMS	TO-7814	soil humate	9,170 ±180
10IH73	NW/22	AMS	TO-7357	bone collagen	10,050 ±180
SR-35A	300-310	AMS	TO-7822	soil humate	10,260 ±640
SR-26	A/1	AMS	TO-7351	charred wood	10,740 ±220
SR-21	Top of Unit 8	AMS	TO-7358	bone collagen	11,310 ±80
SR-26	A/2	AMS	TO-7352	charred wood	11,320 ±90
10IH73	A/SE/RC2	AMS	Beta-114949	wood charcoal	11,370 ±40
10IH73	SW/18	AMS	TO-7349	wood charcoal	11,410 ±130
10IH73	73/609/A/SE/L30	AMS	Beta-109971	bone collagen	12,020 ±170
SR-27	Unit 6	AMS	TO-7819	soil humate	12,220 ±310
SR-23	190-200 cm	AMS	TO-7817	soil humate	13,090 ±750
SR-23	280-290	AMS	TO-7818	soil humate	14,930 ±1030
SR-26	Strat. Unit 2	Radiometric	Tx-9137	soil humate	25,270 ±530

APPENDIX B. SELECTED PEDOLOGIC FIELD DESCRIPTIONS AND RESULTS OF GRANULOMETRIC ANALYSES

Headings for tables in this section are defined in the following manner (after Harden 1982; Soil Survey Staff 1993): Unit = observed stratigraphic unit (used instead of sampling at a given depth interval (e.g., 10 cm)), Depth (cm) refers to the stratigraphic span of the Unit or sample; LB = lower boundary between observed stratigraphic units (g = gradual, c = clear, a = abrupt (considered the same as "sharp"), s = smooth, w = wavy, i = irregular); Dry color = Munsell color chart (Macbeth Division of Kollmorgen Instruments Corporation 1994) determination of soil color at dry condition (nearly all sections observed in field were considered to be dry); Tex. = texture (determined by hand texturing method or from results of laboratory granulometry analyses (see Soil Survey Staff 1993 for quantitative boundaries for textural classes) (f = fine, m = medium, c = coarse, C = clay, CL = clay loam, SiL = silt loam, L = loam, Si = silt, S = sand); CF = clay films (frequency: 1 = few, 2 = common, 3 = many; thickness: n = thin, mk = moderately thick, k = thick; morphology: pf = ped face coatings, br = bridging grains, po = pore linings, co = coats on clasts (thus, 1mkpo would translate to "few, moderately thick clay films seen as pore linings"); ST = structure (grade: m = massive, sg = single grained, 1 = weak, 2 = moderate, 3 = strong; size: vf = very fine, f = fine, m = medium, c = coarse, vc = very coarse; type: gr = granular, pl = platey, pr = prismatic, cpr = columnar, abk = angular blocky, sbk = subangular blocky (thus, 2mabk would translate to "moderately developed, medium angular blocky structure"); DC = dry consistency (lo = loose, so = soft, sh = slightly hard, h = hard, vh = very hard, eh = extremely hard); MC = moist consistency (lo = loose, vfr = very friable, fr = friable, fi = firm, vfi = very firm, efi = extremely firm). Granulometry size categories follow Wentworth (1922) and include: FP = fine pebble; GR = granule; VCS = very coarse sand; CS = coarse sand; MS = medium sand; FS = fine sand; VFS = very fine sand; S+C = silt and clay. Profile description nomeclature follows Soil Survey Staff (1993) and Birkeland (1984). Clast roundness was typically described in the field, following Folk (1955). Granulometric determinations were made in the laboratory in the following manner: 100.0 g samples of sediment were disaggregated by hand, using a mortar and pestle when needed, oven-dried (60° C (140° F)) for 24 hours, and poured into a stack of wire mesh sieves (U.S. Standard Sieve sizes 5, 10, 35, 60, 120, 230, and Pan), which were mechanically shaken for 15 minutes;

afterwards, the contents of each sieve was weighed. Blank sections in tables or empty parentheses denote the absence of data; the presence of a dash (--) signals the absence of observable information (i.e., not applicable) in profile. For example, clay films were not frequently observed in canyon sections, thus most tables include a dashed line to show that information in this category could not be found. As well, gravelly deposits were not typically sampled for granulometric analyses, nor would most pedogenic descriptors apply.

Unit	Depth (cm)	LB	Dry color	Tex.	CF	ST	DC	MC
1	0-30	cw						
1a	50-180	cs	10YR6/3	fSi	--	1msbk	so	lo
2	30-65	cs						
3	50-65	cs	10YR7/3	fSi	--	m	lo	lo
4	65-150	cw	10YR8/1	fSi	--	m	lo	lo
5	65-150	cw	10YR4/3	mSCL	3mkpf, br, po,co	3cabk	eh	vfi
6	100-200		10YR5/3	mSL	--	1msbk	h	fr
7	150-200		2.5Y5/4	mS	--	m	sh	vfr

SR-14 pedology description (established from field descriptions and in lab from samples).

Unit	FP	GR	VCS	CS	MS	FS	VFS	S+C	Munsell color (dry)
1	60.9	5.1	4.7	4.6	4.2	8.7	7.1	5.3	10YR2/2
2									
3	0.0	0.3	0.2	3.8	13.3	39.9	25.8	16.7	10YR3/3
4	0.2	0.1	0.1	2.4	8.1	33.7	34.9	20.3	10YR4/2
4a	0.0	0.3	0.4	7.1	22.2	30.8	23.5	15.7	10YR3/2
5	0.9	0.3	0.5	10.3	29.3	29.3	17.8	12.9	10YR3/3
6									
7	0.0	0.0	0.1	0.7	2.7	21.6	54.7	20.9	10YR6/3
8	0.0	0.0	0.1	0.5	1.5	32.9	33.6	32.5	10YR5/2
9	0.0	0.0	0.0	0.4	3.3	8.9	66.8	21.1	10YR6/2
10									
11	0.0	0.0	0.0	0.4	1.0	18.4	64.1	16.1	10YR6/2
12									
13	0.0	0.0	0.0	0.0	0.3	41.9	32.4	25.0	10YR7/2
14	0.0	0.0	0.0	0.0	0.2	18.1	40.0	41.4	10YR7/2
15									
16									
17	0.0	0.0	0.0	0.4	8.0	27.5	59.3	12.0	10YR6/2
18	0.0	0.1	0.1	0.1	0.3	26.8	58.1	14.9	10YR6/2

SR-21 granulometry data with Munsell soil colors.

Unit	FP	GR	VCS	CS	MS	FS	VFS	S+C
1	6.5	2.3	6.3	9.4	8.1	29.2	16.6	21.3
2	39.8	6.3	9.6	11.4	7.3	5.9	11.8	7.6
3	39.2	8.4	11.1	12.2	8.1	8.8	6.0	6.4
4	15.0	4.8	9.8	15.8	14.3	15.6	12.7	11.9
5	1.2	4.0	11	17.1	11.4	15.7	16.3	22.1
6	0.6	1.7	6.0	14.7	14.7	20.4	19.4	22.5
7	1.1	1.0	4.4	12.4	16.0	23.0	24.5	16.5
8	0.0	0.1	0.5	11.9	15.7	25.3	17.3	28.3
9	0.0	0.0	0.3	19.3	16.8	17.3	21.5	24.6
10	0.2	0.0	1.7	29.5	11.6	18.9	13.0	25.2
11	1.1	0.1	0.5	12.9	20.2	19.2	18.2	27.5
12	5.8	0.3	0.5	8.6	23.5	28.9	16.8	15.5
13	1.2	0.0	0.0	1.3	37.6	48.2	9.5	2.4
13a	0.9	0.1	0.3	8.1	22.7	26.8	23.5	16.4

SR-22 granulometry data.

Unit	Horizon	LB	Dry Col. Tex.	CF	ST	DC	MC
1			10YR4/3	--	1fsbk	so	lo
2			10YR4/3	--			
3			10YR5/3	--	1fsbk	sh	lo
4			10YR4/4	--	1msbk	sh	lo
5			10YR6/4	--	1msbk	sh	lo
6			10YR5/4	--	1msbk	sh	lo
7			10YR4/4	--	1fsbk	sh	lo
8			10YR4/4	--	1msbk	sh	lo
9			10YR5/4	--	1msbk	sh	lo
10			10YR5/4	--	1msbk	sh	lo
11			10YR4/4	--	1msbk	sh	lo
12			10YR5/4	--	1msbk	sh	lo
13			10YR6/4	--	m	lo	lo
13a			10YR5/4	--	1msbk	sh	lo

SR-22 pedologic description.

Unit	Horizon	Depth (cm)	LB	Dry color	Tex.	CF	ST	DC	MC
0-10	A	0-10		10YR3/6	fL	--	2fsbk	sh	vfr
10-20	A	10-20		10YR3/6	fL	--	2fsbk	sh	vfr
20-30	Bt	20-30		10YR3/6	fL	1n, pf,br, po	2fsbk	h	vf
30-40	Bt	30-40	cs	10YR3/6	fL	2n,pf,br, po	2mcpr	vh	fi
40-50	Bt	40-50		10YR5/4	fCL	2n,pf,br, po	2mcpr	vh	fi
50-60	Bt	50-60		10YR5/4	fCL	2n,pf,br, po	2mcpr	vh	fi
60-70	Bt	60-70		2.5Y5/4	fCL	v1,br,po	2mcpr	vh	fi
70-80	Cca	70-80	cs	2.5Y6/4	fL	--	3csbk	h	fr
80-90	Cca	80-90		2.5Y6/4	fSL	--	3csbk	h	fr
90-100	Cca	90-100		2.5Y6/4	fSL	--	3csbk	h	fr
100-110	Cca	100-110		10YR6/4	fSL	--	3csbk	vh	fi
110-120	C	110-120		10YR6/4	fSL	--	2msbk	h	fr
120-130	C	120-130		10YR6/4	fSL	--	2msbk	sh	vfr
130-140	C	130-140		10YR6/4	fSL	--	2msbk	sh	vfr
140-150	C	140-150	gw	10YR6/4	fSL	--	2msbk	sh	vfr
150-160	2C	150-160		10YR6/4	fSL	--	2msbk	sh	vfr
160-170	2C	160-170		10YR5/4	fSL	--	2msbk	h	fr
170-180	2C	170-180	gw	10YR5/6	fL	--	2msbk	h	fr
180-190	2Bb	180-190		10YR6/4	fSL	--	2msbk	h	fr
190-200	2Bb	190-200		10YR5/4	fSL	--	2msbk	vh	fi
200-210	2Bb	200-210	cs	10YR5/4	fSL	--	2msbk	h	fr
210-220	2Bkb	210-220		10YR6/4	fSL	--	2msbk	h	fr
220-230	2Bkb	220-230	ci	10YR5/6	fSL	--	2msbk	h	fr
230-240	3C	230-240		10YR5/4	fSL	--	1fsbk	h	fr
240-250	3C	240-250	gs	10YR6/4	fL	--	1fsbk	h	fr
250-260	3C	250-260		10YR5/4	fL	--	1fsbk	h	fr
260-270	3C	260-270		10YR5/6	fL	--	1fsbk	h	fr
270-280	3C	270-280		10YR5/6	fSL	--	1fsbk	h	fr
280-290	3C	280-290		10YR5/4	fL	--	1fsbk	sh	vfr
290-300	3C	290-300		10YR5/6	fL	--	1fsbk	sh	vfr
300-310	3C	300-310		10YR5/6	fL	--	1fsbk	sh	vfr
310-320	3C	310-320	gw	10YR5/6	fL	--	1fsbk	sh	vfr
320-330	3Bwb	320-330		10YR5/6	fSL	--	1fsbk	sh	vfr
330-340	3Bwb	330-340		10YR5/6	fL	--	1fsbk	sh	vfr
340-350	3Bwb	340-350	cw	10YR5/6	fSL	--	1fsbk	h	fr
350-360	4C	350-360		10YR5/6	fSL	--	1fsbk	h	fr
360-370	4C	360-370		10YR5/6	fL	--	1fsbk	sh	vfr
370-380	4C	370-380		10YR6/4	fL	--	1fsbk	sh	vfr
380-390	4C	380-390		10YR6/4	fL	--	m	sh	vfr
390-400	4C	390-400		10YR6/4	fL	--	1fsbk	sh	vfr
400-410	4C	400-410		10YR6/3	fL	--	1fsbk	h	fr
410-420	4C	410-420		10YR6/3	fSL	--	1msbk	h	fr

SR-23 pedology description (established from field descriptions and in lab from samples).

Depth	CS	MS	FS	VFS	S+C
10	1.3	2.6	15.1	26.5	54.5
20	1.5	4.7	14.7	26.8	50.6
30	0.0	3.8	12.4	23.5	55.2
40	1.0	6.8	13.2	23.7	54.7
50	1.0	1.3	6.5	36.9	53.9
60	0.7	1.1	3.7	34.0	60.0
70	0.8	1.2	7.1	30.3	60.6
80	2.2	1.5	12.0	33.0	51.3
90	2.0	1.8	5.8	30.4	60.0
100	0.6	1.1	7.9	25.9	63.9
110	0.5	5.1	10.4	26.8	56.7
120	0.1	0.7	5.3	28.7	64.6
130	0.4	0.4	5.4	36.5	57.3
140	0.2	2.1	13.0	31.7	52.7
150	0.1	0.4	8.9	36.0	54.2
160	0.3	0.4	7.1	48.0	43.6
170	0.4	3.0	17.6	36.1	42.4
180	2.0	1.2	9.0	38.6	49.1
190	2.5	4.2	19.1	37.4	36.3
200	2.1	4.0	22.1	34.5	37.0
210	1.9	5.1	20.8	37.6	34.4
220	1.3	7.3	13.3	36.3	41.2
230	1.8	7.4	20.4	37.9	32.1
240	1.2	3.3	12.6	32.8	48.3
250	1.2	2.1	15.8	32.8	46.7
260	1.5	3.1	16.2	31.4	47.8
270	1.4	3.2	13.5	40.9	40.1
280	0.6	2.1	12.3	34.0	48.1
290	0.9	1.7	11.6	32.1	53.2
300	1.2	1.8	11.1	32.1	53.0
310	1.7	3.8	12.6	28.4	52.6
320	1.2	2.0	11.4	31.9	52.7
330	1.0	1.7	9.8	42.2	44.5
340	1.4	1.6	12.8	35.6	48.5
350	1.1	1.9	19.1	34.4	43.4
360	5.3	4.6	15.1	30.3	43.7
370	1.0	2.3	16.2	32.4	49.5
380	5.1	5.1	13.9	27.7	47.5
390	1.1	2.3	17.0	29.8	49.3
400	0.9	2.6	18.4	32.1	45.7
410	1.3	2.3	13.9	31.0	48.3
420	4.3	9.6	18.1	29.1	38.2

SR-23 granulometry data.

SR-24 Profile Description

Unit 1: Dark brown (10YR3/3) silt loam, columnar blocky, slightly sticky, slightly plastic, firm, common subangular to angular fine pebble to coarse cobbles, clear smooth boundary

Unit 2: Light brownish gray (10YR6/2) silty textured volcanic tephra, massive, nonsticky, nonplastic, firm, few subangular to angular pebbles, clear wavy boundary

Unit 3: Brown (10YR4/3) silt, subangular blocky, nonsticky, nonplastic, firm, common subangular to angular fine pebbles to coarse cobbles, common fine carbonate nodules, clear smooth boundary

Unit 4: Yellowish brown (10YR5/4) silt, subangular blocky, nonsticky, nonplastic, firm, few fine to coarse subrounded to subangular pebbles, common fine carbonate nodules, clear wavy boundary

Unit 5: Abundant subangular to angular fine pebble to coarse cobble clast-supported matrix with fine to coarse pebble and brown (10YR5/3) silt loam interstitial matrix, nonsticky, nonplastic, firm, carbonate coats finer clasts, clear wavy boundary

Unit 6: Abundant subangular to angular fine pebbles (~90%) with few coarse cobbles, well sorted clast supported matrix, loose, sharp wavy boundary

Unit 7: Yellowish brown (10YR5/4) silt loam, angular blocky, nonsticky, nonplastic, firm, common fine subangular to angular pebbles, gradual smooth boundary

Unit 8: Light yellowish brown (10YR6/4) silt loam, massive, nonsticky, nonplastic, firm, sharp irregular boundary

Unit 9: Abundant subrounded to subangular fine pebble to coarse cobble, predominantly clast-supported matrix with few areas of light yellowish brown (10YR6/4) silt loam, massive, nonsticky, nonplastic, firm, sediment, sharp irregular boundary

Unit 10: White (10YR8/1) carbonaceous silt loam mixed with yellowish brown (10YR5/4) silt loam, angular blocky, nonsticky, nonplastic, firm, clear wavy boundary

Unit 11: Yellowish brown (10YR5/4) silt loam and light yellowish brown (10YR6/4) mixed (bioturbated?) and bedded in discontinuous horizontal layers, nonsticky, nonplastic, firm

Depth	FP	G	VCS	CS	MS	FS	VFS	S+C
0-10	0.0	0.0	0.0	0.3	0.7	4.7	22.0	72.2
10-20	0.0	0.0	0.0	0.2	0.9	5.9	28.5	64.4
20-30	0.0	0.0	0.0	0.2	0.4	2.7	27.8	68.6
30-40	0.0	0.0	0.0	0.2	0.6	3.5	22.2	73.3
40-50	0.0	0.0	0.1	00.3	0.6	3.1	18.0	77.6
50-60	0.1	0.1	0.1	0.2	0.6	4.3	30.6	63.7
60-70	0.0	0.0	0.0	0.1	0.7	3.3	28.1	67.5
70-80	0.0	0.0	0.1	0.2	0.6	2.9	29.6	66.5
80-90	0.3	0.3	0.3	0.4	0.4	3.2	18.4	76.7

SR-26-3 granulometry data.

Unit	Depth* (cm)	LB	Dry color	Text.	CF	ST	DC	MC
1	0	aw						
2	0-95	cw	10YR5/6	fSiL	--	m	so	lo
2a	80-85	as	10YR4/4					
3	95-105	ci	10YR6/3	mS	--	m	lo	lo
4	105-120	cs	2.5Y5/4	mSl	--	m	lo	lo
5	120-125	as	10YR6/2	mSiL	--	m	lo	lo
6	125-140	aw	10YR6/2	S	--	m	lo	lo
7	140-150	as	10YR6/2	mSiL	--	m	lo	lo
8	150-160	aw	10YR6/2	S	--	m	lo	lo
9	160-175	as	10YR6/2	S	--	m	lo	lo
10	175-180	as	10YR5/2	mSiL	--	m	lo	lo
11a	180-185	ai	2.5Y4/4	fSiL	1nbr	1msbk	sh	vfr
11b	185-189	ai	2.5Y5/4	mSiL	--	m	so	lo
11c	189-193	ai	2.5Y4/4	fSiL	1nbr	1msbk	sh	vfr
11d	193-198	ai	2.5Y5/4	mSiL	--	m	so	lo
11e	198-202	ai	2.5Y4/4	fSiL	1nbr	1msbk	sh	vfr
11f	202-206	ai	2.5Y5/4	mSiL	--	m	so	lo
11g	206-210	ai	2.5Y4/4	fSiL	1nbr	1msbk	sh	vfr
11h	210-215	ai	2.5Y5/4	mSiL	--	m	so	lo
11i	215-219	ai	2.5Y4/4	fSiL	1nbr	1msbk	sh	vfr
11j	219-225	ai	2.5Y5/4	mSiL	--	m	so	lo
12	225-237	cs	2.5Y4/4	mSiL	2br,po,co	2msbk	sh	vfr
13	237-244	cs						
14	244-258	ci	2.5Y4/4	fSiL	--	1msbk	so	lo

SR-26-3 pedology description (established from field descriptions and in lab from samples). *below Unit 1

Depth	FP	GR	VCS	CS	MS	FS	VFS	S+C
20	0.0	0.1	0.2	0.7	3.3	13.4	23.3	58.6
30	0.0	0.0	0.5	1.7	5.9	15.7	34.2	41.5
40	0.0	0.2	0.2	2.0	2.4	12.4	29.7	52.6
50	0.0	0.0	0.1	1.7	2.9	8.0	27.1	60.0
60	0.5	0.0	0.2	0.3	2.2	5.2	23.8	67.4
70	0.5	0.3	0.6	1.7	4.2	7.4	26.4	58.3
80	0.0	0.0	0.2	0.7	4.8	16.2	28.3	49.4
90	0.0	0.0	0.0	1.3	0.8	13.1	56.2	28.3
100	0.0	0.0	0.1	0.5	1.2	9.0	54.6	34.3
110	0.1	0.1	0.2	0.4	1.1	6.0	36.2	55.5
120	4.0	0.8	0.8	0.8	1.1	5.8	22.8	63.1
130	1.0	0.1	0.2	0.9	1.3	6.5	23.9	65.7
140	0.0	0.1	0.2	0.4	1.0	7.1	26.2	64.6
150	0.2	0.1	0.4	0.6	1.8	5.2	47.7	43.6
160	0.4	0.1	0.2	0.5	0.7	3.5	32.1	61.6
170	0.6	0.1	0.4	0.8	1.9	8.6	46.3	41.1
180	1.5	0.4	0.5	1.5	3.9	10.1	28.6	53.4

SR-26-5 granulometry data.

Unit	FP	GR	VCS	CS	MS	FS	VFS	S+C	Dry Col.	Tex
2	1.6	0.2	0.5	0.3	0.1	26.4	35.8	34.7	10YR6/4	sl
3	1.4	0.3	0.4	0.6	2.1	27.4	44.6	23.9	10YR5/4	sl
4	0.0	0.1	0.3	0.1	0.1	36.1	40.4	22.9	10YR5/4	sl
5	13.0	0.8	1.1	1.5	5.4	13.9	38.8	25.8	10YR5/3	l
6	0.8	0.8	0.8	1.4	6.8	25.8	40.6	23.6	10YR5/3	sl
7	0.1	0.1	0.2	1.0	8.2	35.8	35.5	19.3	10YR6/3	sl
7a	1.0	0.2	0.2	1.5	10.8	34.9	31.9	19.7	10YR6/3	sl
8	0.1	0.1	0.3	2.5	10.0	45.6	23.2	14.7	10YR6/3	sl

SR-27 granulometry data.

Depth	CS	MS	FS	VFS	S+C
10	65.5	8.4	13.5	8.2	4.0
20	52.9	14.1	18.6	10.6	1.6
30	43.2	14.0	20.8	8.0	6.6
40	38.5	15.8	23.9	16.5	5.8
50	39.0	17.0	26.3	14.1	3.4
60	33.2	12.2	21.9	28.8	3.4
70	23.7	11.4	38.4	23.7	1.5
80	27.7	11.1	22.9	31.8	4.1
90	27.5	11.6	31.2	25.6	2.0
100					
110					
120					
130					
140	12.9	11.2	32.3	28.4	14.5
150	13.2	9.2	46.5	27.2	4.2

SR-30 granulometry data.

Depth	CS	MS	FS	VFS	S+C
10	9.8	22.7	43.6	18.4	3.9
20					
30	3.6	13.8	49.2	26.6	8.1
40	3.9	12.3	49.8	26.6	6.3
50	6.2	22.2	51.4	17.7	3
60					
70					
80	10.1	23.5	48.7	15.4	2.6
90					
100					
110					
120					
130					
140					
150					
160					
170					
180	4.7	9	20.6	53.3	11.3
190	22.1	13.6	40.1	20.8	2
200	8.9	7.6	21.8	53.7	7.8
210					
220					
230					
240	36.5	41.3	13.2	6	1.6
250					
260					
270	17.6	29.6	40.4	12.2	0.1
280					
290					
300					
310	18.6	6.9	24.7	39.2	7

SR-33 granulometry data.

Unit	LB	Dry Color	Tex.	CF	ST	DC	MC
0-10			10YR3/4	--	1msbk	so	lo
10-20			10YR3/4	--	1msbk	so	lo
20-30			10YR4/2	--	1msbk	so	lo
30-40			10YR4/3	--	1msbk	so	lo
40-50							
50-60			10YR4/3	--	1msbk	so	lo
60-70			10YR4/3	--	1msbk	so	lo
70-80			10YR5/4	--	2msbk	sh	vfr
80-90			10YR5/3	--	1msbk	sh	vfr
90-100							
100-110							
110-120			10YR5/4	--	2msbk	h	fr
120-130			10YR5/4	--	2msbk	sh	vfr
130-140			10YR5/4	--	2msbk	sh	vfr
140-150							
150-160							
160-170			10YR6/3	--	1msbk	sh	vfr
170-180			10YR6/3	--	1msbk	sh	vfr
180-190			10YR6/3	--	1msbk	sh	vfr
190-200							
200-210			10YR6/2	--	1msbk	so	lo
210-220			10YR6/2	--	1msbk	so	lo
220-230			10YR6/2	--	1msbk	so	lo
230-240			10YR6/2	--	1msbk	so	lo
240-250			10YR6/2	--	1msbk	so	lo
250-260			10YR6/2	--	1msbk	so	lo
260-270			10YR6/4	--	1msbk	sh	vfr
270-280			10YR6/4	--	1msbk	sh	vfr
280-290			10YR5/4	--	1mabk	sh	vfr
290-300							
300-310			10YR5/4	--	1mabk	sh	vfr
310-320			10YR5/4	--	2csbk	sh	vfr
320-330							
330-340			10YR5/4	--	2msbk	sh	vfr
340-350			10YR5/4	--	2msbk	sh	vfr
350-360			10YR5/4	--	2msbk	sh	vfr
360-370			10YR5/4	--	2msbk	h	fr
370-380			10YR5/4	--	2msbk	h	fr
380-390			10YR5/4	--	2msbk	h	fr
390-400			10YR5/4	--	2msbk	h	fr
400-410			10YR6/4	--	2msbk	h	fr
410-420			10YR6/6	--	2msbk	h	fr
420-430			10YR6/4	--	2msbk	sh	vfr
430-440			10YR5/4	--	1msbk	sh	vfr
440-450			10YR6/4	--	1msbk	sh	vfr
450-460			10YR6/4	--	1msbk	sh	vfr
460-470			10YR6/4	--	1msbk	sh	vfr
470-480			10YR6/3	--	1msbk	sh	vfr
480-490			10YR6/3	--	1msbk	sh	vfr
490-500			10YR6/3	--	1msbk	sh	vfr

SR-34 pedology description (established from field descriptions and in lab from samples).

Depth	Horizon	LB	Dry Col. Tex.	CF	ST	DC	MC
0-10			10YR4/6	--	1msbk	sh	lo
10-20			10YR4/6	--	1msbk	sh	lo
20-30							
30-40			10YR4/6	v1npf	2msbk	sh	lo
40-50			10YR5/6	--	1msbk	sh	lo
50-60			10YR5/4	--	1msbk	sh	lo
60-70			10YR5/4	--	1msbk	so	lo
70-80			10YR5/4	--	1msbk	so	lo
80-90			10YR6/4	--	1msbk	so	lo
90-100			10YR6/4	--	1msbk	so	lo
100-110			10YR6/4	--	1msbk	so	lo
110-120			10YR6/4	--	1msbk	so	lo
120-130			10YR6/4	--	1msbk	so	lo
130-140			10YR6/4	--	1msbk	sh	lo
140-150			10YR6/4	--	1msbk	sh	lo
150-160			10YR6/4	--	1msbk	sh	lo
160-170							
170-180			10YR6/4	--	1msbk	sh	lo
180-190			10YR6/3	--	1mabk	sh	lo
190-200			10YR6/4	--	1msbk	sh	lo
200-210			10YR6/4	--	1mabk	sh	lo
210-220			10YR6/4	--	1msbk	sh	lo
220-230			10YR6/4	--	1msbk	sh	lo
230-240							
240-250			10YR6/4	--	1msbk	sh	lo
250-260			10YR6/4	--	1mabk	sh	lo
260-270			10YR6/4	--	1mabk	sh	lo
270-280			10YR6/4	--	1mabk	sh	lo
280-290			10YR6/4	--	1mabk	sh	lo
290-300			10YR6/4	--	1mabk	sh	lo
300-310							
310-320			10YR5/6	--	1mabk	sh	lo
320-330			10YR5/6	--	1mabk	sh	lo
330-340			10YR5/6	--	1mabk	sh	lo
340-350			10YR5/4	--	1mabk	sh	lo
350-360							
360-370			10YR5/6	--	1mabk	sh	lo
370-380							
380-390							
390-400			10YR5/4	--	1msbk	sh	lo
400-410			10YR5/4	--	1msbk	sh	lo
410-420							
420-430			10YR5/4	--	1msbk	sh	lo
430-440							
440-450			10YR5/4	--	1msbk	sh	lo
450-460			10YR5/4	--	1msbk	sh	lo
460-470			10YR5/4	--	1msbk	sh	lo
470-480			10YR5/4	--	1msbk	sh	lo
480-490							
490-500							
500-510							
510-520			10YR5/4	--	1msbk	sh	lo
520-530							
530-540							

SR-35 pedologic description (established from field descriptions and in lab from samples).

Depth	FP	G	VCS	CS	MS	FS	VFS	S+C
10	5.6	0.0	1.7	8.6	12.7	13.1	25.5	32.5
20	0.3	0.1	0.4	11.4	9.4	7.9	27.9	42.4
30	1.3	0.0	0.1	12.1	15.6	13.7	24.8	32.2
40	0.0	0.0	0.0	6.9	15.2	17.4	27.5	33.0
50	0.0	0.0	0.1	7.3	13.8	9.7	31.7	37.3
60	0.0	0.0	0.1	0.6	19.1	12.9	30.8	36.5
70	0.0	0.0	0.1	0.8	17.0	13.0	21.5	47.4
80	0.0	0.1	0.1	0.4	9.8	10.6	28.4	50.4
90								
100	0.0	0.0	0.1	0.3	9.9	10.7	33.1	45.8
110	0.0	0.0	0.1	0.1	0.2	0.9	46.9	51.3
120	0.1	0.3	0.8	1.2	4.2	8.1	35.4	49.4
130	14.7	0.9	1.5	3.3	5.2	10.3	24.0	39.9
140	0.4	0.2	0.6	2.3	3.4	6.1	32.2	54.8
150	1.8	0.3	1.3	24	16.3	16.4	19.2	20.9
160	4.7	0.8	3.0	13.6	19.2	23.3	17.0	18.0
170	0.6	1.2	4.6	17.4	15.8	19.7	22.4	17.8
180	2.2	1.2	4.9	20.8	8.9	8.9	26.9	25.0
190	0.1	0.1	0.4	0.8	0.9	2.8	29.2	65.3
200								
210	9.6	2.5	10.3	21.1	11.6	13.8	12.5	18.3
220	1.4	3.0	11.6	20.0	12.8	14.6	16.8	19.0
230	10.8	4.0	7.8	16.8	9.1	7.8	22.8	19.8
240	1.7	2.6	8.1	16.4	12.4	13.5	20.3	25.2
250	4.3	2.2	7.8	14.2	12.6	13.7	22.5	22.1
260	13.3	2.9	6.7	13.5	11.4	13.1	17.2	21.7
270	6.2	1.5	5.5	12.2	12.3	13.5	23.5	24.5
280	3.9	0.9	4.1	9.2	9.1	12	31.9	28.2
290	0.9	0.8	2.7	6.6	11.3	18.9	30.5	27.7
300	1:9	1.5	3.6	7.2	5.2	15.9	19.5	44.5
310	0.9	1.4	3.0	4.9	6.8	11.5	26.8	44.8
320	14.2	1.6	2.0	8.3	7.8	15.2	23.0	28.2
330	1.8	0.9	1.7	14.2	7.4	16.9	22.1	35.3
340								
350	0.3	0.3	0.7	5.8	2.0	17.7	24.0	49.6
360	1.3	0.4	1.2	6.8	5.8	9.0	31.5	44.2
370	10.3	0.6	1.5	2.9	3.6	7.4	23.5	50.1
380	0.7	0.5	0.9	2.3	3.3	5.7	26.1	60.5
390	0.1	0.1	0.5	0.1	1.7	3.9	30.7	62.6
400	6.0	0.3	0.6	0.8	0.9	0.3	51.0	39.2
410	2.0	0.6	1.0	15.0	1.6	2.2	29.3	61.1
420	3.5	0.5	1.6	1.7	2.5	4.3	36.6	49.8
430	0.7	0.3	0.8	1.4	1.5	6.9	22.8	66.7
440	0.2	0.4	0.7	3.1	3.2	5.3	37.4	49.5
450	30.4	1.2	3.9	21.9	7.5	15.9	8.6	10.5
460	2.7	0.4	1.1	1.6	2.3	6.7	28.3	57.2
470	1.2	0.6	0.7	2.7	3.1	0.8	54.9	36.1
480	1.3	0.7	1.4	2.3	2.9	7.9	26.4	56.1
490	0.1	0.2	0.5	1.3	2.2	1.5	55.4	38.0
500	4.9	2.0	8.2	20.7	12.8	14.1	15.1	22.4
510	0.0	0.2	0.3	0.3	0.5	3.3	37.2	58.4
520	0.0	0.0	0.1	0.2	0.6	3.4	32.4	63.7
530	0.5	0.0	0.1	0.1	0.2	5.3	28.9	64.5
540	0.0	0.0	0.1	0.2	0.5	4.4	44.5	50.2
550	0.0	0.0	0.0	0.1	0.3	3.0	37.8	58.4
560	0.2	0.1	0.2	1.2	3.3	15.7	44.7	34.6

570	0.0	0.1	0.0	0.1	0.8	9.4	44.5	44.9
580	0.0	0.0	0.0	0.1	0.1	23.9	35.2	40.3
590	0.0	0.0	0.1	0.4	1.0	11.1	40.6	46.5
600	0.0	0.1	0.1	1.7	2.0	8.2	28.5	59.3
610	0.2	0.6	0.9	1.5	1.8	5.5	31.2	58.2
620	0.0	0.1	0.2	0.9	1.9	4.8	41.7	50.3
630	0.0	0.1	0.4	5.5	5.8	9.2	41.0	37.8
640	0.0	0.2	0.9	3.2	4.3	5.6	52.2	32.1
650	1.0	0.5	2.0	8.1	3.1	20.6	25.4	39.2
660	12.1	1.2	3.7	18.9	9.4	0.4	36.9	16.3
670	10.4	1.8	6.2	14	10.0	11.9	19.2	26.0
680	5.1	2.9	7.9	12.7	8.5	12.7	23.9	25.6
690	71.1	1.8	7.9	21.5	9.7	24.5	26.4	36.3
700	21.8	2.1	5.4	7.2	6.6	10.8	23.0	22.1
710	4.3	1.2	4.9	10.3	5.8	21.3	22.1	30.0
720	2.4	1.7	6.8	11.4	12.2	17.7	31.3	16.1
730	20.1	7.2	16	14.8	8.4	9.7	11.9	12.0
740	23.4	5.4	10.8	11.6	7.7	11.1	13.4	16.7
750	4.4	3.6	7.1	10.3	7.1	16.9	20.2	30.2
760	29.8	13.9	17.6	8.3	5.5	3.6	23.7	18.8
770	22.9	3.3	6.9	8.6	6.7	15.6	21.2	14.8
780	14.5	3.1	7.7	10.6	10.8	14.0	23.6	15.6
790	7.7	3.5	8.3	10.8	5.2	21.0	19.1	24.2
800	17.3	3.5	7.5	8.6	5.7	0.2	34.3	22.0
810	26.8	7.7	14.6	18.8	8.2	37	40.7	46.0
820	60.0	2.4	4.1	4.3	3.6	6.1	10.0	9.3
830	34.6	4.7	7.1	6.8	5.6	9.0	14.3	18.1
840	19.9	2.4	5.8	7.0	6.6	9.0	23.7	25.1

SR-35 granulometry data.

Unit	FP	GR	VCS	CS	MS	FS	VFS	S+C
1	0.0	0.0	0.0	0.3	13.8	23.9	31.5	29.9
5	0.0	0.0	0.0	0.8	1.7	27.1	37.1	32.7
6	0.0	0.0	0.0	2.1	4.6	13.9	52.8	26.4
7	0.0	0.0	0.0	0.6	1.8	10.4	49.3	38.0
8	0.0	0.0	0.0	0.4	1.8	14.0	35.5	48.0
9	0.0	0.0	0.0	1.9	1.6	7.9	33.9	55.1
10	5.4	2.5	4.5	24.9	37.2	18.8	3.7	2.3

SR-40-1 granulometry data.

Depth	FP	GR	VCS	CS	MS	FS	VFS	S+C
10	0.0	0.2	0.4	1.8	6.1	15.5	35.9	39.8
20	0.0	0.0	0.1	1.4	5.2	14.7	32.7	45.2
30	0.0	0.0	0.1	0.4	1.3	6.7	42.7	48.4
40	0.2	0.1	0.2	1.5	1.1	8.5	39.9	48.0
50	0.0	0.2	0.1	0.1	1.1	8.1	38.6	51.5
60	0.0	0.0	0.0	0.1	0.9	7.9	45.9	44.9
70	0.0	0.0	0.0	0.6	3.0	11.6	45.3	39.2
80	0.0	0.1	0.3	2.3	10.4	26.8	35.2	24.4
90	0.0	0.0	0.0	0.8	4.1	15.2	35.6	43.6
100	0.0	0.0	0.1	0.7	3.8	19.8	39.0	36.4
110	0.0	0.0	0.0	0.1	0.5	6.8	48.7	43.6
120	0.0	0.0	0.1	0.4	0.8	9.6	45.8	42.6
130	0.2	0.0	0.1	0.2	0.5	7.4	44.3	46.9
140	0.6	0.6	0.3	0.3	1.0	9.3	55.1	31.8
150	1.9	0.1	0.3	0.3	1.2	10.8	53.7	31.6
160	0.1	0.1	0.3	0.2	0.7	9.9	55.0	33.7
170	0.6	0.1	0.4	0.4	1.9	14.9	58.3	23.5
180	5.6	0.4	0.4	0.3	1.6	12.6	45.5	33.0
190	0.2	0.0	0.1	0.0	1.1	13.3	62.6	22.4
200	0.0	0.1	0.0	0.0	0.9	13.6	62.5	22.8
210	1.2	0.0	0.1	0.0	0.3	10.0	50.4	38.0
220	0.0	0.0	0.0	0.1	0.5	8.7	57.1	33.4
230	0.0	0.0	0.0	0.0	0.6	7.5	63.4	28.3
240	0.0	0.0	0.0	0.0	0.8	9.8	49.6	39.6
250	0.0	0.2	0.1	0.1	1.2	11.0	49.3	37.8
260	0.1	0.1	0.1	0.1	1.4	14.0	44.1	39.8
270	0.0	0.1	0.3	0.6	1.6	19.3	47.5	30.5
280	0.1	0.2	0.3	0.8	2.9	21.0	50.8	23.5
290	0.0	0.1	0.2	0.3	1.8	25.6	48.5	23.2
300	0.2	0.1	0.2	0.3	2.9	36.8	39.8	19.7

SR-41 granulometry data.

SR-42 Profile Description

0-35 cm: Very dark brown (10YR2/2) loamy sand, massive, abundant roots, nonsticky, nonplastic, loose, gradual smooth boundary

35-60 cm: Very dark grayish brown (10YR3/2) loamy sand, massive, common roots, nonsticky, nonplastic, loose, gradual smooth boundary

60-260 cm: Dark brown (10YR3/3) sand, massive, few roots, nonsticky, nonplastic, loose, 2-4 cm thick horizontal beds of fine and medium sand and subrounded pebbles, few rodent burrows, sharp irregular boundary

260-263 cm: Dark grayish brown (10YR4/2) sand, massive, nonsticky, nonplastic, loose, sharp irregular boundary

263-300 cm: Dark yellowish brown (10YR3/4) clay loam, subangular blocky, slightly sticky, slightly plastic, friable, common fine carbonate filaments, common fine subrounded to subangular pebbles, clear wavy boundary

300-315 cm: Dark yellowish brown (10YR3/4) clay loam, subangular blocky, slightly sticky, slightly sticky, friable, common fine carbonate filaments, clear smooth boundary

315-325 cm: Brown (10YR4/3) loam, subangular blocky, nonsticky, nonplastic, friable, common fine carbonate filaments, clear irregular boundary

325-365 cm: Light gray (10YR7/2) sand textured volcanic tephra, massive, nonsticky, nonplastic, loose, rare small rodent burrows, sharp irregular boundary

365-385 cm: Dark yellowish brown (10YR3/4) loam, subangular blocky, nonsticky, nonplastic, friable, abundant fine to coarse rounded to subrounded pebbles, common fine carbonate filaments, clear smooth boundary

385-415 cm: Dark yellowish brown (10YR4/3) loam, subangular blocky, nonsticky, nonplastic, friable, few fine to medium rounded to subrounded pebbles, common fine carbonate filaments, clear wavy boundary

415-486 cm: Grayish brown (10YR5/2) sand, massive, nonsticky, nonplastic, loose, sharp smooth boundary

486-500 cm: Dark yellowish brown (10YR3/4) loam, subangular blocky, nonsticky, nonplastic, friable, common fine to medium subangular pebbles, common carbonate filaments

SR-43 Profile Description

0-25 cm: Very dark brown (10YR2/2) loamy sand, massive, abundant roots, nonsticky, nonplastic, loose, gradual smooth boundary

25-50 cm: Very dark grayish brown (10YR3/2) loamy sand, massive, common roots, nonsticky, nonplastic, loose, gradual smooth boundary

50-115 cm: Very dark brown (10YR2/2) fine subangular to subrounded pebble to subangular coarse cobble clast-supported matrix with interstitial sandy clay loam sediment, slightly sticky, slightly plastic, friable, clear wavy boundary

115-137 cm: Dark yellowish brown (10YR3/4) loamy sand, massive, nonsticky, nonplastic, friable, abundant very fine to coarse subrounded to subangular pebbles, clear wavy boundary

137-175 cm: Light gray (10YR7/2) loamy sand textured volcanic tephra, massive, nonsticky, nonplastic, loose, few fine to coarse subrounded to subangular pebbles, clear wavy boundary

175-207 cm: Dark yellowish brown (10YR3/4) sandy loam, subangular blocky, nonsticky, nonplastic, friable, common fine to coarse subrounded to angular pebbles and fine to medium subrounded to angular cobbles, gradual smooth boundary

207-225 cm: Olive brown (2.5YR4/4) loamy sand, massive, nonsticky, nonplastic, loose, common fine subrounded to subangular pebbles, clear smooth boundary

225-310 cm: Brown (10YR5/3) sand, massive, nonsticky, nonplastic, loose, rare fine subrounded to subangular pebbles, few rodent burrows, sharp wavy boundary

310-415 cm: Dark yellowish brown (10YR3/4) loam, subangular blocky, nonsticky, nonplastic, loose, few fine to coarse subrounded to angular pebbles and cobbles, clasts increase with depth, carbonate covers base of most clasts, clear wavy boundary

415-450 cm: Yellowish brown (10YR5/4) loamy sand, massive, nonsticky, nonplastic, loose, common fine carbonate filaments, clear wavy boundary

450-462 cm: ( ) loamy sand, massive, nonsticky, nonplastic, friable, few fine to medium pebbles, common fine carbonate filaments, clear wavy boundary

462-481 cm: ( ) fine loamy sand, massive, nonsticky, nonplastic, friable, common fine carbonate filaments, sharp wavy boundary

481-491 cm: ( ) silty loam, subangular blocky, slightly sticky, slightly plastic, friable, common fine to coarse subrounded to subangular pebbles, common fine carbonate filaments, clear smooth boundary

491-507 cm: ( ) loamy sand, massive, nonsticky, nonplastic, friable, few fine to coarse subrounded to subangular pebbles, clear wavy boundary

507-509 cm: ( ) discontinuous sand textured volcanic tephra layer, massive, nonsticky, nonplastic, loose, common fine carbonate filaments, few fine to coarse subrounded to subangular pebbles, sharp discontinuous boundary

509-524 cm: ( ) clast-supported fine to coarse subrounded to angular pebbles with loamy sand matrix, nonsticky, nonplastic, loose, abundant fine carbonate filaments, sharp smooth boundary

524-526 cm: ( ) loamy sand, massive, nonsticky, nonplastic, friable, sharp irregular boundary

526-529 cm: ( ) sand textured tephra, massive, nonsticky, nonplastic, friable, sharp irregular boundary

529-536 cm: ( ) loamy sand, massive, nonsticky, nonplastic, friable, sharp smooth boundary

536-558 cm: ( ) sandy loam, massive, slightly sticky, nonplastic, friable, bioturbation evident, clear wavy boundary

558-612 cm: ( ) loamy sand, massive, nonsticky, nonplastic, loose, few fine carbonate filaments, sharp discontinuous boundary

612-614 cm: ( ) loamy sand, massive, nonsticky, nonplastic, friable, rip-up clasts, few fine carbonate filaments, sharp discontinuous boundary

614-620 cm: ( ) loamy sand, massive, nonsticky, nonplastic, loose, few fine carbonate filaments, sharp discontinuous boundary

620-622 cm: ( ) silt, massive, nonsticky, nonplastic, friable, abundant dispersed carbonate, sharp discontinuous boundary

622-634 cm: ( ) loamy sand, massive, nonsticky, nonplastic, loose, few fine carbonate filaments, sharp discontinuous boundary

634-645 cm: ( ) silty sand, massive, slightly sticky, nonsticky, friable, abundant dispersed carbonate, sharp smooth boundary

645-664 cm: ( ) clast-supported subrounded to angular fine pebble to fine cobble matrix with interstitial loamy sand sediment, nonsticky, nonplastic, loose

Depth	FP	GR	VCS	CS	MS	FS	VFS	S+C
1-115	0.0	0.0	0.0	3.2	10.8	46.6	25.5	13.6
115-137	20.7	8.1	8.6	10.1	5.0	9.8	12.2	24.8
137-175	8.9	2.1	3.4	3.7	2.4	7.4	17.4	54.5
175-207	12.7	6.2	5.7	6.9	5.2	13.0	24.3	26.1
207-225	6.9	1.2	1.8	3.1	5.5	23.8	35.2	22.9
225-310	0.0	0.0	0.0	0.1	3.0	40.8	39.7	16.3
310-415	19.9	8.1	6.1	5.4	4.8	13.3	22.6	19.8
415-450	0.9	0.7	1.3	1.9	4.7	35.6	38.0	16.7
450-460	6.2	2.2	2.0	2.6	4.0	24.3	31.5	26.6
462-481	0.0	0.2	0.2	0.5	3.4	25.8	50.2	19.3
481-491	36.0	5.5	6.4	4.8	3.9	8.7	16.9	18.0
491-507	1.0	1.1	1.5	2.8	6.0	18.7	25.7	42.7
507-524	17.5	10.9	20.1	16.3	7.4	7.5	8.8	11.4
524-536	0.0	0.2	0.1	0.3	0.7	13.6	35.7	49.3
536-558	0.4	0.2	0.1	0.4	1.0	17.2	31.0	49.3
558-612	0.0	0.0	0.0	0.1	1.0	17.9	53.9	27.2
612-620	0.0	0.0	0.0	0.1	0.2	14.1	46.8	38.4
620-622	0.0	0.1	0.1	0.2	0.6	14.7	35.2	48.4
622-634	0.0	0.0	0.0	0.1	0.7	7.5	57.4	34.5
634-645	0.0	0.1	0.2	0.3	0.6	10.1	28.8	59.1
645+	0.0	0.0	0.0	0.1	1.7	18.3	61.3	18.3

SR-43 granulometry data.

10IH1312 Profile Description

Unit 1 (0-12 cm): Very dark grayish brown (10YR3/2) loamy sand, weak subangular blocky, nonsticky, nonplastic, friable, few angular fine to coarse pebbles, common fine roots, clear wavy boundary

Unit 2 (12-30 cm): Very dark brown (10YR2/2) loam, weak subangular blocky, nonsticky, nonplastic, friable, rare angular fine to coarse pebbles, few fine roots, gradual wavy boundary

Unit 3 (30-50 cm): Very dark brown (10YR2/2) loam, weak subangular blocky, nonsticky, nonplastic, friable, rare angular fine to coarse pebbles, very few fine roots, gradual wavy boundary

Unit 4 (50-85 cm): Very dark grayish brown (10YR3/2), silt loam, weak subangular blocky, nonsticky, nonplastic, friable, rare fine roots, clear wavy boundary

Unit 5 (85-115 cm): Subangular to angular fine pebble to boulder clast-supported matrix with interstitial dark yellowish brown (10YR4/4) sand.

Unit	FP	GR	VCS	CS	MS	FS	VFS	S+C
1	10.7	0.9	1.6	6.5	16.8	30.9	15.4	17.5
2	13.2	0.5	0.8	4.5	17.2	23.2	18.3	21.7
3	17.0	0.3	0.5	4.4	16.4	20.2	15.6	25.1
4	0.7	0.7	0.7	6.5	21.1	28.4	17.3	23.7
5	63.8	1.1	0.8	1.2	7.1	12.2	7.3	6.3

10IH1312 Unit A granulometry data.

Depth	FP	G	VCS	CS	MS	FS	VFS	S+C
10	0.0	0.1	0.9	8.3	21.7	45.5	17.0	6.0
20	0.0	0.1	0.2	2.3	8.6	53.8	21.7	9.5
30	0.0	0.1	0.0	1.1	11.5	50.7	30.9	5.7
40	2.4	0.3	0.8	1.4	1.8	9.9	21.3	62.3
50	1.4	0.4	1.0	2.5	1.7	4.7	25.1	63.3
60	4.5	0.4	0.8	1.8	1.6	4.2	24.9	61.7
70								
80	1.7	1.0	1.5	2.6	2.3	4.2	22.6	63.5
90	0.1	0.3	0.9	1.5	1.6	4.7	26.0	64.7
100	6.3	0.7	1.2	2.5	1.9	4.7	17.8	64.2
110	0.9	1.4	1.5	2.9	1.4	6.7	22.3	61.5
120	1.3	0.5	1.5	2.8	2.6	7.1	31.3	52.1
130	2.2	1.5	2.3	3.7	1.4	7.8	23.2	56.6
140	3.1	1.3	1.4	3.5	4.0	8.4	34.2	41.3
150	1.4	1.1	1.5	3.9	5.2	9.7	30.8	46.0
160	1.5	0.6	1.5	3.7	5.7	11.7	29.9	45.3

10IH2491 Unit D granulometry data.

Depth	FP	GR	VCS	CS	MS	FS	VFS	S+C
10	0.0	0.8	1.5	6.5	26.2	45.5	14.0	5.7
20	0.7	0.9	0.9	14.5	32.4	36.2	11.9	3.1
30	0.8	0.7	2.6	16.7	34.5	32.6	9.0	4.0
40	0.0	0.0	0.0	17.1	33.3	37.0	9.6	3.1
50	0.4	2.8	4.4	11.9	29.0	33.0	12.5	7.8
60	32.9	4.4	4.3	4.5	4.0	1.2	22.8	27.4
70	5.3	6.5	6.8	9.7	7.0	11.4	22.0	32.3
80	8.5	6.3	5.8	6.6	5.0	13.4	19.5	37.4
90	0.0	0.0	0.0	39.5	4.6	8.9	15.5	30.9
100	0.0	21.6	5.1	5.0	5.2	12.1	17.6	34.2
110	0.0	0.0	0.0	18.7	4.5	12.0	19.0	46.2
120	2.5	2.6	3.2	3.4	4.4	10.0	21.9	53.5
130	0.0	0.0	0.0	7.5	3.0	7.0	28.1	55.1
140	7.1	1.7	1.4	2.0	2.9	8.6	20.5	56.0
150	2.3	1.0	0.6	2.3	2.1	3.7	32.3	55.5
160								
170	1.0	0.9	1.5	1.7	2.3	12.3	20.2	59.9
180	0.0	0.0	0.0	2.3	2.5	8.3	21.0	64.7
190	0.0	0.0	0.0	11.3	3.2	14.7	31.1	38.4
200	1.1	1.1	1.7	2.9	3.7	23.4	37.5	29.9
210	0.0	0.4	0.7	1.0	2.2	13.9	39.1	44.7
220	0.0	0.0	0.0	2.1	2.6	15.8	35.2	45.3
230	0.0	0.0	0.3	2.1	3.6	20.3	26.1	34.0
240	0.1	0.8	5.2	15.7	12.6	19.8	21.4	25.0
250	0.0	0.0	0.0	3.5	4.3	17.3	30.6	44.5
260	0.0	0.0	0.0	0.4	0.8	2.7	24.8	70.4

10IH1220 granulomtery data.

Unit	FP	GR	VCS	CS	MS	FS	VFS	S+C
7	0.0	0.0	0.0	1.0	9.7	47.4	32.1	9.6
8	0.0	0.0	0.0	0.5	6.9	48.3	27.6	16.2
9	0.0	0.0	0.0	0.2	6.7	29.6	28.3	35.0
11	0.0	0.0	0.0	1.8	29.8	49.3	14.0	3.4
13	0.0	3.7	9.4	11.6	22.9	24.1	15.5	11.2
15	0.0	0.0	0.0	3.3	36.9	48.0	9.9	1.5
16	0.0	0.0	0.0	2.0	36.3	42.0	14.4	5.6
17	0.0	0.0	0.0	0.8	11.8	21.2	27.6	39.7
21	0.0	0.0	0.0	1.9	17.2	36.4	28.9	15.3

10IH395 Unit B granulometry data.

Depth	FP	GR	VCS	CS	MS	FS	VFS	S+C
10	0.0	0.0	0.2	0.9	10.0	44.1	29.0	15.6
20	0.0	0.0	0.3	0.9	8.6	45.1	34.3	10.7
30	0.0	0.0	0.3	0.7	6.6	48.4	33.0	10.7
40	0.0	0.0	0.2	0.7	6.6	48.9	32.6	10.7
50	0.0	0.0	0.2	0.9	12.9	59.2	19.6	6.5
60	0.0	0.0	0.1	2.4	13.9	58.6	20.1	4.5
64	0.0	0.0	0.3	1.4	17	54.9	20.7	5.7
80								
90								
100	0.0	0.0	0.0	0.2	4.7	34.6	39.6	21.1
110								
120								
130								
140	0.0	0.0	0.0	0.4	17.1	60.8	17.7	4.0

PB 1 granulomtery data.

Depth	FP	GR	VCS	CS	MS	FS	VFS	S+C
20	0.0	0.0	0.0	0.2	5.7	36.4	42.6	14.9
30	0.0	0.0	0.0	0.1	3.6	36.5	41.0	18.0
40	0.0	0.0	0.0	0.1	2.8	30.1	42.9	24.1
50	0.0	0.0	0.0	0.3	2.4	39.1	44.4	13.3
60	0.0	0.0	0.0	0.2	2.9	52.4	32.6	11.3
70	0.0	0.0	0.0	0.1	4.7	42.4	43.6	9.0
80	0.0	0.0	0.0	0.3	3.9	50.9	36.6	8.0
90	0.0	0.0	0.0	0.2	7.3	59.3	25.4	7.4
100	0.0	0.0	0.0	0.2	10.9	60.1	21.8	6.8
110	0.0	0.0	0.0	0.2	14.9	56.3	24.6	4.6
120	0.0	0.0	0.0	0.6	18.4	63.5	13.9	4.0
130	0.0	0.0	0.0	0.3	11.1	63.4	19.5	5.2
140								
150	0.0	0.0	0.0	0.4	15.7	64.2	15.0	4.0
160	0.0	0.0	0.0	0.2	13.9	64.4	16.5	4.5
170	0.0	0.0	0.0	0.5	19.9	61.0	15.3	3.6
180	0.0	0.0	0.0	0.8	17.4	64.3	13.3	3.7
190	0.0	0.0	0.0	1.7	19.8	58.5	15.9	4.3
200	0.0	0.0	0.0	0.4	5.0	44.4	40.1	10.2
210	0.0	0.0	0.0	0.3	1.9	35.7	51.6	10.3
220	0.0	0.0	0.0	1.8	3.6	38.8	45.5	10.4

PB 2 granulometry data.

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APPENDIX C. MAGNETIC SUSCEPTIBILITY DATA

Magnetic susceptibility of sediments was recorded in the field with a portable Bartington MS2 susceptibility meter equipped with an MS2F probe, which was operated at a frequency of 0.58 kHz. The probe sensor was placed in contact with dry sediments in profile and susceptibility was measured *in situ*, with care taken to avoid taking readings next to rocks (which would give different results than sediments). After recording each reading, the probe sensor was cleaned of adhering sediment. Every so often a measurement was made on a clay plug with a known susceptibility value to calibrate the equipment. Data shown below are reported in SI units, organized by depth relative to stratigraphic section.

Depth	SR-21	SR-22	SR-23	SR-26	SR-27	SR-30
5	256		204	182	159	270
10	197		209	185	172	210
15	186		201	182	184	196
20	189		204	176	194	220
25	182		212	176	191	252
30	198		226	220	185	246
35	208		259	193	181	241
40	263		230	208	166	255
45	276		230	181	160	243
50	282		217	201	134	244
55	279		193	187	164	261
60	260		189	168	148	230
65	250		199	201	127	219
70	239		198	274	124	211
75	236		190	179	120	211
80	228		190	186	119	217
85	225		182	165	115	215
90	222		171	144	128	213
95	215	416	172	180	128	191
100	217	450	185	212	123	191
105	219	404	176	205	115	196
110	193	402	171	152	130	173
115	191	415	147	169	156	178
120	167	507	182	158	133	174
125	165	491	173	124	191	177
130	162	472	182	150	200	183
135	172	455	199	118	197	173
140	186	423	196	118	200	192
145	206	484	191	91	206	214
150	229	450	174	87	203	191
155	232	424	168	106	210	199
160	198	380	189	83	199	176

165	132	354	190	206	184	181
170	106	369	215	204	178	197
175	151	399	185	160	187	181
180	188	327	198	152	153	162
185	334	358	205	183	114	147
190	308	291	207	181	120	158
195	247	295	221	254	120	139
200	140	235	196	255	218	154
205	128	231	212	272	218	169
210	122	290	198	174	201	169
215	125	280	184	158	184	164
220	117	314	222	425	191	174
225	156	310	202	339	200	155
230	420	309	204	156	194	146
235	353	321	197	157	154	145
240	168	257	185	234	158	148
245	190	238	180	210	183	138
250	154	222	194	208	183	142
255	142	212	195	201	175	143
260	147	305	203	221	182	143
265	121	335	204	224	183	146
270	155	294	205	198	178	153
275	91	287	206	201	188	151
280	113	309	203	175	181	140
285	111	304	207	179	193	139
290	127	383	230	171	192	150
295	120	391	218		193	169
300	108	400	242		195	147
305		383	237		244	170
310		277	245		201	176
315		284	245		211	182
320		268	265		189	160
325		257	263		257	169
330		210	252			174
335		143	265			173
340			273			187
345			258			186
355			262			169
360			253			174
365			258			183
370			230			174
375			238			183
380			221			202
385			218			182
390			214			182
395			225			184
400			229			178
405			210			188
410			214			182
415			188			249
420			165			237
425						246
430						241
435						188

440	227
445	215
450	200
455	214
460	201
465	210
470	214
475	164

APPENDIX D. ELECTRON MICROPROBE DATA ON TEPHRA SAMPLES

Electron microprobe analyses (EMA) were conducted on tephra samples from the Lower Salmon River Canyon, based on methods developed by Smith and Westgate (1969). Tephra samples were dried and mounted in an epoxy resin plug, which was polished and coated with a thin layer of carbon. EMA of tephra samples were made at the University of Alberta Department of Earth and Atmospheric Sciences with a JXA-8900R WD/ED Combined Microanalyzer. Operating parameters included an accelerator voltage of 15.0 Kv, beam current of 10.0 -8 Å, and a beam diameter of 3 micrometers. The elemental data resulting from the EMA was recorded as weight percent in oxides. Data shown below are not normalized to 100%.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
71.69	0.46	14.40	1.84	0.04	0.42	1.71	4.56	2.60	97.73	grain 1/1
72.09	0.45	14.50	2.05	0.04	0.44	1.66	4.34	2.76	98.32	grain 1/2
72.22	0.46	14.51	2.04	0.03	0.43	1.56	4.26	2.69	98.20	grain 1/3
71.73	0.49	14.16	2.03	0.04	0.45	1.63	4.10	2.70	97.32	grain 2/1
72.51	0.52	14.34	1.96	0.05	0.48	1.69	4.29	2.75	98.60	grain 2/2
72.88	0.51	14.33	1.93	0.06	0.45	1.69	4.31	2.71	98.87	grain 2/3
73.34	0.42	14.52	1.98	0.04	0.46	1.66	4.48	2.74	99.64	grain 3/1
72.94	0.45	14.69	1.95	0.06	0.43	1.64	4.48	2.63	99.28	grain 3/2
72.80	0.44	14.63	1.99	0.06	0.41	1.63	4.57	2.65	99.18	grain 4/1
72.87	0.43	14.51	1.92	0.02	0.46	1.73	4.62	2.87	99.43	grain 4/2
72.18	0.49	14.16	1.88	0.03	0.42	1.55	4.57	2.77	98.05	grain 5/1
73.47	0.42	14.53	2.02	0.05	0.44	1.55	4.34	2.75	99.56	grain 5/2
72.49	0.50	14.56	1.99	0.03	0.49	1.67	4.35	2.76	98.82	grain 6/1
72.83	0.42	14.37	2.02	0.04	0.45	1.65	4.21	2.82	98.82	grain 6/2
72.63	0.47	14.54	1.93	0.07	0.42	1.67	4.53	2.72	98.98	grain 6/3
72.10	0.43	14.48	1.98	0.06	0.39	1.53	4.40	2.71	98.09	grain 7/1
72.11	0.46	14.43	1.91	0.02	0.44	1.62	4.40	2.77	98.15	grain 7/2
72.92	0.48	14.55	1.95	0.05	0.45	1.61	4.47	2.62	99.09	grain 8/1
72.84	0.45	14.57	1.96	0.07	0.44	1.65	4.58	2.59	99.15	grain 8/2
72.66	0.49	14.49	1.91	0.04	0.44	1.62	4.44	2.62	98.71	grain 8/3

SR-42 tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
73.87	0.15	12.04	1.00	0.04	0.19	1.04	3.14	3.39	94.87	grain 1/1
74.25	0.26	12.02	1.00	0.02	0.16	1.03	3.24	3.34	95.32	grain 1/2
74.56	0.18	12.06	1.06	0.06	0.19	1.10	3.09	3.49	95.78	grain 1/3
73.11	0.19	12.17	1.19	0.03	0.30	1.41	3.79	2.79	94.98	grain 3/1
73.16	0.21	12.24	1.13	0.03	0.26	1.34	3.74	2.90	95.01	grain 3/2
73.31	0.24	12.33	1.10	0.05	0.28	1.29	3.15	2.93	94.67	grain 5/1
74.21	0.26	12.25	1.07	0.03	0.29	1.33	3.14	3.00	95.57	grain 5/2
73.96	0.20	12.32	1.05	0.02	0.26	1.32	3.41	2.89	95.43	grain 6/1
75.27	0.14	12.55	1.03	0.04	0.27	1.33	2.91	3.04	96.57	grain 6/2
74.76	0.19	12.26	1.08	0.04	0.23	1.34	2.93	2.98	95.81	grain 6/3
75.41	0.15	12.49	1.08	0.04	0.27	1.34	2.94	2.96	96.67	grain 6/4

SR-43 tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
71.709	0.428	14.315	1.517	0.062	0.444	1.741	3.430	2.917	96.563	grain 1/1
72.41	0.428	14.408	1.566	0.041	0.494	1.572	3.645	2.798	97.362	grain 1/2
72.554	0.463	14.616	1.538	0.064	0.442	1.640	3.873	3.046	98.236	grain 1/3
72.076	0.402	14.174	1.506	0.048	0.429	1.682	3.698	2.892	96.907	grain 2/2
72.393	0.486	14.400	1.606	0.054	0.452	1.713	4.033	3.018	98.155	grain 3/1
71.472	0.446	14.463	1.579	0.059	0.432	1.527	3.621	2.95	96.549	grain 3/2
71.416	0.426	14.457	1.501	0.050	0.405	1.698	3.621	2.858	96.432	grain 3/3

10IH2491 Unit D tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
71.811	0.158	13.466	1.764	0.070	0.121	0.721	4.580	3.338	96.029	grain 1/3
71.987	0.195	13.476	1.754	0.075	0.136	0.762	3.870	3.071	95.326	grain 2/1
71.748	0.155	13.263	1.832	0.070	0.113	0.724	4.071	3.115	95.091	grain 2/2
71.706	0.161	13.404	1.743	0.036	0.120	0.733	4.005	3.170	95.078	grain 2/3
71.700	0.169	13.481	1.693	0.061	0.112	0.713	4.177	2.951	95.057	grain 3/2
71.788	0.118	13.480	1.813	0.047	0.117	0.755	4.349	2.865	95.332	grain 3/3

SR-40 tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
73.368	0.450	14.745	1.889	0.051	0.418	1.687	3.343	2.626	98.577	grain 1-1
71.727	0.398	14.442	1.862	0.048	0.441	1.636	3.821	2.786	97.161	grain 1-2
70.954	0.450	14.259	1.867	0.026	0.457	1.533	3.742	2.686	95.974	grain 2-1
70.960	0.467	14.365	1.944	0.036	0.428	1.631	4.128	2.697	96.656	grain 2-2
72.294	0.471	14.411	1.857	0.049	0.362	1.516	3.294	2.732	96.986	grain 3-1
72.631	0.402	14.362	1.795	0.060	0.313	1.552	4.056	2.792	97.963	grain 3-2
72.446	0.475	14.582	1.961	0.068	0.498	1.690	3.632	2.666	98.018	grain 4-1
72.652	0.474	14.692	1.927	0.044	0.486	1.672	4.155	2.628	98.730	grain 4-2
72.236	0.425	14.119	1.990	0.049	0.496	1.600	2.627	2.725	96.267	grain 5-1
72.004	0.420	14.410	1.937	0.048	0.431	1.605	3.896	2.753	97.504	grain 5-2
71.540	0.406	14.563	1.824	0.066	0.440	1.617	3.839	2.629	96.924	grain 6-1
71.955	0.452	14.409	1.943	0.056	0.458	1.634	3.835	2.673	97.415	grain 6-2
73.268	0.458	14.637	1.992	0.061	0.458	1.794	2.822	2.690	98.180	grain 7-1
71.955	0.415	14.644	1.967	0.039	0.501	1.665	4.163	2.778	98.127	grain 7-2
72.022	0.466	14.200	1.830	0.070	0.409	1.457	3.450	2.613	96.517	grain 8-1
71.814	0.432	14.271	1.832	0.051	0.375	1.412	4.260	2.811	97.258	grain 8-2
71.267	0.418	14.065	1.778	0.037	0.444	1.628	3.998	2.648	96.283	grain 9-1
70.471	0.417	14.093	1.884	0.039	0.502	1.606	3.733	2.655	95.400	grain 9-2
70.820	0.420	14.026	1.830	0.101	0.419	1.531	3.573	2.700	95.420	grain 9-3
72.906	0.472	14.677	1.963	0.049	0.469	1.636	3.845	2.717	98.734	grain 10-1
71.766	0.418	14.410	1.926	0.077	0.488	1.702	4.144	2.671	97.602	grain 10-2

SR-14 tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
70.860	0.613	15.139	2.690	0.053	0.700	2.498	3.836	2.995	99.384	grain 1-1
68.440	0.696	14.844	2.643	0.032	0.713	2.312	3.833	2.974	96.487	grain 1-2
69.008	0.687	14.161	2.492	0.038	0.623	2.199	3.557	2.962	95.727	grain 2-1
68.686	0.707	14.035	2.465	0.025	0.617	2.092	3.606	2.993	95.226	grain 2-2
68.483	0.556	17.294	2.072	0.021	0.526	3.809	4.630	2.520	99.911	grain 3-1
57.178	0.093	26.754	0.519	0.000	0.039	9.389	6.938	0.319	101.229	grain 3-2
69.641	0.655	15.043	2.595	0.020	0.737	2.443	3.874	3.023	98.031	grain 4-1
68.454	0.558	14.818	2.784	0.043	0.714	2.431	3.973	2.959	96.734	grain 4-2
73.438	0.449	12.035	1.441	0.005	0.144	0.811	2.956	3.611	94.890	grain 5-1
63.130	0.179	20.493	1.564	0.000	0.791	5.297	7.353	1.216	100.023	grain 5-2
68.621	0.593	14.808	2.652	0.052	0.760	2.379	3.720	2.913	96.498	grain 6-1
68.610	0.689	14.612	2.634	0.023	0.664	2.438	3.688	2.998	96.356	grain 6-2
69.178	0.619	15.066	2.729	0.038	0.708	2.429	4.048	2.966	97.781	grain 7-1
68.638	0.692	14.850	2.719	0.030	0.767	2.460	3.903	2.955	97.014	grain 7-2
69.273	0.631	14.912	2.308	0.053	0.555	2.278	4.444	2.904	97.358	grain 8-1
68.978	0.692	14.310	2.579	0.034	0.640	2.163	4.526	2.767	96.689	grain 8-2
68.878	0.626	14.378	2.520	0.039	0.675	2.262	3.480	3.057	95.915	grain 9-1
68.165	0.685	14.265	2.565	0.041	0.657	2.386	3.466	2.922	95.152	grain 9-2
69.742	0.700	14.761	2.760	0.031	0.715	2.507	1.576	2.884	95.676	grain 10-1
69.948	0.642	14.714	2.689	0.030	0.842	2.381	1.135	2.827	95.208	grain 10-2
68.705	0.594	14.852	2.582	0.047	0.731	2.458	2.504	2.625	95.098	grain 1-1
67.933	0.686	14.918	2.817	0.076	0.773	2.644	3.098	2.727	95.672	grain 1-2
69.054	0.645	14.996	2.914	0.083	0.847	2.524	4.110	2.870	98.043	grain 2-1
69.246	0.646	15.025	2.855	0.063	0.702	2.561	4.021	2.817	97.936	grain 2-2
67.852	0.695	14.763	2.732	0.067	0.716	2.344	3.865	2.831	95.865	grain 3-1
68.783	0.649	14.739	2.757	0.047	0.717	2.414	4.105	2.902	97.113	grain 3-2
68.235	0.626	14.671	2.709	0.034	0.644	2.489	3.481	2.764	95.653	grain 3-3
69.230	0.610	14.213	2.818	0.067	0.769	2.231	3.985	2.840	96.763	grain 4-1
69.186	0.624	14.593	2.787	0.056	0.750	2.357	3.934	2.863	97.150	grain 4-2
68.669	0.665	15.094	2.896	0.042	0.776	2.485	3.866	2.783	97.276	grain 5-1
68.657	0.649	14.965	2.891	0.053	0.785	2.497	3.637	2.936	97.070	grain 5-2
69.380	0.660	14.299	2.666	0.070	0.655	2.057	3.932	3.053	96.772	grain 6-1
70.643	0.642	14.333	2.774	0.049	0.652	2.106	3.621	3.095	97.915	grain 6-2
68.156	0.674	14.624	2.714	0.065	0.710	2.338	3.548	2.866	95.695	grain 7-1
67.919	0.686	14.777	2.559	0.062	0.708	2.276	3.512	2.923	95.422	grain 7-2
67.997	0.669	14.827	2.850	0.074	0.750	2.391	3.636	2.772	95.966	grain 8-1
67.890	0.582	14.657	2.827	0.032	0.707	2.418	3.886	2.842	95.841	grain 8-2
69.163	0.625	15.204	2.893	0.039	0.764	2.543	3.792	2.778	97.801	grain 9-1
69.055	0.688	15.131	2.940	0.060	0.758	2.470	3.987	2.852	97.941	grain 9-2
68.163	0.645	14.922	2.843	0.044	0.787	2.510	3.632	2.900	96.446	grain 10-1
69.084	0.734	14.869	2.922	0.061	0.802	2.475	3.184	2.868	96.999	grain 10-2

SR-26-3 unit 10 tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
70.145	0.586	15.138	3.027	0.054	0.807	2.500	3.166	2.971	98.394	grain 1-1
68.875	0.585	15.067	2.960	0.052	0.767	2.565	3.836	2.906	97.613	grain 1-2
55.688	0.000	27.682	0.666	0.012	0.095	10.328	6.713	0.286	101.47	grain 2-1
68.371	0.612	14.280	2.782	0.102	0.714	2.109	3.318	3.073	95.361	grain 2-2
69.520	0.580	14.380	2.760	0.059	0.713	2.148	3.620	3.108	96.888	grain 2-3
69.514	0.609	14.371	2.812	0.060	0.704	2.199	3.679	3.013	96.961	grain 2-4
66.160	0.553	14.364	2.708	0.071	0.700	2.484	3.218	2.752	93.010	grain 3-1
67.740	0.599	14.760	2.677	0.051	0.755	2.395	3.186	2.735	94.898	grain 3-2
69.264	0.612	14.053	2.805	0.030	0.671	2.040	3.684	2.977	96.136	grain 4-1
68.749	0.582	14.148	2.776	0.064	0.679	2.162	3.656	2.912	95.728	grain 4-2
68.105	0.657	14.699	2.912	0.065	0.657	2.392	4.145	2.847	96.479	grain 5-1
68.353	0.646	14.635	2.824	0.061	0.798	2.447	4.218	2.944	96.926	grain 5-2
67.970	0.601	14.787	2.847	0.060	0.765	2.380	3.785	2.844	96.039	grain 5-3
68.018	0.518	14.837	2.897	0.059	0.747	2.443	3.451	3.002	95.972	grain 6-1
67.562	0.598	14.748	2.902	0.056	0.783	2.449	3.614	2.864	95.576	grain 6-2
67.143	0.571	14.638	2.820	0.040	0.815	2.398	3.145	2.828	94.398	grain 6-3
68.487	0.564	14.283	2.744	0.040	0.664	2.077	3.591	2.982	95.432	grain 7-1
68.050	0.669	14.254	2.745	0.029	0.774	2.146	3.245	3.055	94.967	grain 7-2
68.667	0.541	14.944	2.944	0.061	0.773	2.585	3.768	2.971	97.254	grain 8-1
68.797	0.569	15.158	3.033	0.049	0.693	2.601	3.852	2.937	97.689	grain 8-2
67.423	0.646	14.804	2.921	0.062	0.788	2.548	3.263	2.920	95.375	grain 9-1
68.513	0.633	14.704	2.993	0.059	0.765	2.443	3.781	2.880	96.771	grain 9-2
68.698	0.664	14.849	3.024	0.078	0.747	2.472	3.639	2.979	97.150	grain 10-1
68.394	0.584	14.970	2.825	0.061	0.727	2.518	3.833	2.986	96.898	grain 10-2

SR-26-5 tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
74.575	0.082	13.246	0.731	0.051	0.231	1.612	2.804	2.406	95.738	grain 1/1
74.772	0.064	13.516	0.774	0.036	0.230	1.643	3.315	2.435	96.785	grain 1/2
74.168	0.115	13.293	0.957	0.049	0.233	1.638	2.960	2.309	95.722	grain 1/3
73.838	0.080	13.219	0.688	0.054	0.252	1.696	2.966	2.537	95.330	grain 2/2
74.267	0.083	13.253	0.616	0.035	0.259	1.703	3.105	2.560	95.881	grain 2/3
73.605	0.131	13.180	0.773	0.030	0.241	1.780	2.801	2.391	94.932	grain 3/1
73.378	0.080	13.358	0.747	0.034	0.224	1.680	2.779	2.389	94.669	grain 3/2
73.115	0.102	13.303	0.772	0.012	0.221	1.695	2.729	2.362	94.311	grain 3/3
74.334	0.077	12.805	0.706	0.040	0.216	1.445	2.789	2.522	94.934	grain 4/2
73.899	0.101	12.758	0.699	0.035	0.226	1.487	2.808	2.558	94.571	grain 4/3

SR-35 tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
73.542	0.431	14.798	2.038	0.058	0.464	1.619	2.121	2.577	97.648	grain 1/1
71.722	0.380	14.282	1.899	0.035	0.445	1.667	4.038	2.683	97.151	grain 1/2
72.780	0.412	14.372	1.903	0.045	0.451	1.591	3.695	2.707	97.956	grain 1/3
72.106	0.335	13.716	1.790	0.072	0.423	1.448	3.359	2.582	95.831	grain 2/1
72.581	0.413	13.811	1.874	0.042	0.438	1.443	3.709	2.535	96.846	grain 2/2
72.959	0.508	14.305	1.940	0.049	0.497	1.520	3.623	2.542	97.943	grain 2/3
71.580	0.430	14.194	1.897	0.066	0.462	1.647	3.567	2.598	96.441	grain 3/1
71.643	0.460	14.226	1.883	0.079	0.446	1.615	3.635	2.684	96.671	grain 3/2
70.959	0.418	14.282	1.908	0.041	0.464	1.533	3.362	2.670	95.637	grain 3/3

10IH1308 Unit 1 75 cm below surface tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
72.816	0.442	14.368	1.915	0.057	0.428	1.630	3.702	2.623	97.981	grain 1/1
72.930	0.450	14.427	1.916	0.047	0.425	1.496	3.758	2.596	98.045	grain 1/2
71.243	0.428	14.339	1.880	0.032	0.456	1.592	3.380	2.672	96.022	grain 1/3
71.459	0.426	14.270	1.856	0.042	0.417	1.528	3.584	2.473	96.055	grain 2/1
71.346	0.388	14.216	1.861	0.015	0.431	1.544	3.607	2.637	96.045	grain 2/2
71.652	0.438	14.385	1.722	0.065	0.456	1.556	3.587	2.554	96.415	grain 2/3
72.456	0.482	14.542	1.883	0.051	0.453	1.663	3.943	2.627	98.100	grain 3/1
72.770	0.444	14.626	1.915	0.062	0.485	1.586	3.959	2.647	98.494	grain 3/2
72.403	0.392	14.456	1.913	0.038	0.448	1.598	3.857	2.692	97.797	grain 3/3

10IH395 Unit B unit 4 tephra data.

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	Comment
71.744	0.486	14.554	2.022	0.081	0.455	1.601	3.992	2.738	97.673	grain 1/1
71.430	0.442	14.488	1.915	0.022	0.454	1.577	4.051	2.684	97.063	grain 1/2
70.809	0.468	14.543	1.796	0.055	0.456	1.615	3.611	2.795	96.148	grain 1/3
70.371	0.427	14.241	1.893	0.036	0.435	1.603	3.631	2.690	95.327	grain 1/4
71.876	0.483	14.501	1.918	0.040	0.410	1.587	3.767	2.923	97.505	grain 2/1
71.531	0.453	14.333	1.907	0.034	0.394	1.539	3.729	2.662	96.582	grain 2/2
71.992	0.422	14.790	1.882	0.046	0.428	1.598	4.111	2.883	98.152	grain 2/3
72.513	0.485	14.831	1.885	0.040	0.395	1.627	3.926	2.761	98.463	grain 2/4
71.464	0.400	14.621	1.919	0.033	0.423	1.568	4.030	2.769	97.227	grain 3/1
71.212	0.382	14.669	1.914	0.069	0.386	1.715	4.007	2.695	97.049	grain 3/2
71.078	0.402	14.419	1.930	0.065	0.456	1.651	3.911	2.735	96.647	grain 3/3
72.916	0.399	14.709	1.866	0.021	0.404	1.640	4.050	2.801	98.806	grain 3/4
71.166	0.460	14.692	1.987	0.040	0.434	1.603	4.242	2.921	97.545	grain 4/1
71.079	0.426	14.647	1.961	0.032	0.434	1.686	4.082	2.956	97.303	grain 4/2
70.259	0.406	14.441	1.880	0.045	0.477	1.705	3.447	2.652	95.312	grain 4/3
70.827	0.415	14.415	1.852	0.027	0.451	1.527	3.606	2.646	95.766	grain 4/4

10IH1220 Unit A tephra data.

References

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APPENDIX E. IDENTIFICATION OF TEPHRA SAMPLES

The results of electron microprobe analyses (EMA) on tephra samples shown in Appendix D are compared with published standards of regional tephras and tephra data provided by Andrei Sarna-Wojcicki of the USGS to establish its identity. Multiple analyses were conducted on several tephra grains to evaluate the reliability of results.

Correlations were made by calculating the similarity coefficient (Borchardt et al. 1972; Busacca et al. 1992) between known standards and the unknown tephra samples provided. For the basis of this study, a similarity coefficient value was considered significant (show in the tables below in bolded numerals) in those cases where it very nearly met or exceeded statistically-established correlation coefficient values for a population with seven degrees of freedom at the 0.001 level, which has an *r* value of 89.82% (Thomas 1986: Table A.11). This value is lower than that suggested by Sarna-Wojcicki et al. (1980) and Davis (1985), who consider similarity coefficient values of 95% or higher to represent good correlations. The difference in these approaches may lie in an aspect of EMA instrument calibration or calibration standard choice. In cases where elemental similarity was seen between tephra layers from the same source (e.g., Glacier Peak B and G tephras), or a strong correlation could not be established the (e.g., Mount St. Helens set S--although my identification was supported by Sarna-Wojcicki of the USGS (written communication, 1999)), the known distributions of tephra lobes (Shipley and Sarna-Wojcicki 1983; L.G. Davis 1995) and their relative chronology were also taken into consideration to make a final identification.

Abbreviations and sources for major-element chemistry of tephra used for comparative standards are as follows: Mazama-O = Mount Mazama set O (aka Crater Lake set O) (J.O. Davis 1978; Sarna-Wojcicki et al. 1983); MSH-Ye = Mount St. Helens set Ye (Crandell and Mullineaux 1978; Sarna-Wojcicki et al. 1983); GP-B = Glacier Peak set B (Porter 1978; Sarna-Wojcicki et al. 1983); GP-G = Glacier Peak set G (Sarna-Wojcicki et al. 1983); MSH-S = Mount St. Helens set S (J.O. Davis 1985); MSH-So = Mount St. Helens set So (Mullineaux et al. 1978 [appears as Mullx et al.]; Sarna-Wojcicki et al. 1981); MSH-Sg = Mount St. Helens set Sg (Mullineaux et al. 1978; Sarna-Wojcicki et al. 1981); MSH-Jy = Mount St. Helens set Jy (Mullineaux et al. 1975; Sarna-Wojcicki et al. 1983); MSH-Mm = Mount St. Helens set Mm (Sarna-Wojcicki, written communication 1999); MSH-Cw = Mount St. Helens set Cw (Sarna-Wojcicki, written communication 1999); MSH-Cy = Mount St. Helens set Cy (Sarna-Wojcicki, written communication 1999).

10IH1220 Tephra

		10IH1220		10IH1220		10IH1220		10IH1220		10IH1220		10IH1220		10IH1220		10IH1220		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	10IH1220	
Standards	SiO2	71.39	TiO2	0.44	Al2O3	14.56	Fe2O3	1.91	MgO	0.43	CaO	1.62	Na2O	3.89	K2O	2.77	Similarity Coefficient	
Mazama-O	70.90	99.31	0.42	95.45	13.90	95.47	2.12	90.09	0.36	83.72	1.50	92.59	4.53	85.87	2.76	99.64	92.77	Mazama-O
MSH-Ye	73.10	97.66	0.15	34.09	13.80	94.78	1.34	70.16	0.34	79.07	1.62	100.00	4.16	93.51	2.03	73.29	80.32	MSH-Ye
GP-B	72.30	98.74	0.25	56.82	12.20	83.79	1.16	60.73	0.24	55.81	1.24	76.54	2.79	71.72	2.86	96.85	75.13	GP-B
GP-G	72.90	97.93	0.20	45.45	12.10	83.10	0.98	51.31	0.19	44.19	1.05	64.81	3.59	92.29	3.30	83.94	70.38	GP-G
MSH-So	74.00	96.47	0.15	34.09	13.00	89.29	1.30	68.06	0.27	62.79	1.38	85.19	3.80	97.69	2.20	79.42	76.62	MSH-So
MSH-Sg	72.60	98.33	0.14	31.82	13.30	91.35	1.40	73.30	0.32	74.42	1.52	93.83	3.90	99.74	2.10	75.81	79.82	MSH-Sg
MSH-Jy	74.40	95.95	0.17	38.64	13.10	89.97	1.31	68.59	0.26	60.47	1.36	83.95	4.33	89.84	2.26	81.59	76.12	MSH-Jy
MSH-Mm	76.88	92.86	0.19	43.18	13.27	91.14	1.26	65.97	0.33	76.74	1.56	96.30	4.08	95.34	2.38	85.92	80.93	MSH-Mm
MSH-Cw	76.81	92.94	0.12	27.27	14.03	96.36	0.91	47.64	0.27	62.79	1.66	97.59	1.66	42.67	2.24	80.87	68.52	MSH-Cw
MSH-Cy	76.15	93.75	0.12	27.27	14.05	96.50	1.03	53.93	0.3	69.77	1.62	100.00	4.32	90.05	2.36	85.20	77.06	MSH-Cy

SR-35 Tephra

		SR-35		SR-35		SR-35		SR-35		SR-35		SR-35		SR-35		SR-35		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-35	
Standards	SiO2	74	TiO2	0.09	Al2O3	13.19	Fe2O3	0.75	MgO	0.23	CaO	1.64	Na2O	2.91	K2O	2.45	Similarity Coefficient	
Mazama-O	70.90	95.81	0.42	21.43	13.90	94.89	2.12	35.38	0.36	63.89	1.50	91.46	4.53	64.24	2.76	88.77	69.48	Mazama-O
GP-B	72.30	97.70	0.25	36.00	12.20	92.49	1.16	64.66	0.24	95.83	1.24	75.61	2.79	95.88	2.86	85.66	80.48	GP-B
GP-G	72.90	98.51	0.20	45.00	12.10	91.74	0.98	76.53	0.19	82.61	1.05	64.02	3.59	81.06	3.30	74.24	76.71	GP-G
MSH-So	74.00	100.00	0.15	60.00	13.00	98.56	1.30	57.69	0.27	85.19	1.38	84.15	3.80	76.58	2.20	89.80	81.49	MSH-So
MSH-Sg	72.60	98.11	0.14	64.29	13.30	99.17	1.40	53.57	0.32	71.88	1.52	92.68	3.90	74.62	2.10	85.71	80.00	MSH-Sg
MSH-Jy	74.40	99.46	0.17	52.94	13.10	99.32	1.31	57.25	0.26	88.46	1.36	82.93	4.33	67.21	2.26	92.24	79.98	MSH-Jy
MSH-Mm	76.88	96.25	0.19	47.37	13.27	99.40	1.26	59.52	0.33	69.70	1.56	95.12	4.08	71.32	2.38	97.14	79.48	MSH-Mm
MSH-Cw	76.81	96.34	0.12	75.00	14.03	94.01	0.91	82.42	0.27	85.19	1.66	98.80	4.32	67.36	2.24	91.43	86.32	MSH-Cw
MSH-Cy	76.15	97.18	0.12	75.00	14.05	93.88	1.03	72.82	0.3	76.67	1.62	98.78	4.32	67.36	2.36	96.33	84.75	MSH-Cy
MSH-C (J.Davis 1985)	72.84	98.43	0.11	81.82	14	94.21	1.03	72.82	0.24	95.83	1.5	91.46	4.1	70.98	2.5	98.00	87.94	MSH-C

10IH2491 Unit D Tephra

		Unit D		Unit D		Unit D		Unit D		Unit D		Unit D		Unit D		Unit D		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	10IH2491 Unit D	
Standards	SiO2	72	TiO2	0.44	Al2O3	14.4	Fe2O3	1.33	MgO	0.44	CaO	1.65	Na2O	3.7	K2O	2.93	Similarity Coefficient	
Mazama-O	70.90	98.47	0.42	95.45	13.90	96.53	2.12	62.74	0.36	81.82	1.50	90.91	4.53	81.68	2.76	94.20	**87.72**	Mazama-O
MSH-Ye	73.10	98.50	0.15	34.09	13.80	95.83	1.34	99.25	0.34	77.27	1.62	98.18	4.16	88.94	2.03	69.28	82.67	MSH-Ye
GP-B	72.30	99.59	0.25	56.82	12.20	84.72	1.16	87.22	0.24	54.55	1.24	75.15	2.79	75.41	2.86	97.61	78.88	GP-B
GP-G	72.90	98.77	0.20	45.45	12.10	84.03	0.98	73.68	0.19	43.18	1.05	63.64	3.59	97.03	3.30	88.79	74.32	GP-G
MSH-So	74.00	97.30	0.15	34.09	13.00	90.28	1.30	97.74	0.27	61.36	1.38	83.64	3.80	97.37	2.20	75.09	79.61	MSH-So
MSH-Sg	72.60	99.17	0.14	31.82	13.30	92.36	1.40	95.00	0.32	72.73	1.52	92.12	3.90	94.87	2.10	71.67	81.22	MSH-Sg
MSH-Jy	74.40	96.77	0.17	38.64	13.10	90.97	1.31	98.50	0.26	59.09	1.36	82.42	4.33	85.45	2.26	77.13	78.62	MSH-Jy
MSH-Mm	76.88	93.65	0.19	43.18	13.27	92.15	1.26	94.74	0.33	75.00	1.56	94.55	4.08	90.69	2.38	81.23	83.15	MSH-Mm
MSH-Cw	76.81	93.74	0.12	27.27	14.03	97.43	0.91	68.42	0.27	61.36	1.66	99.40	1.66	44.86	2.24	76.45	71.12	MSH-Cw
MSH-Cy	76.15	94.55	0.12	27.27	14.05	97.57	1.03	77.44	0.3	68.18	1.62	98.18	4.32	85.65	2.36	80.55	78.67	MSH-Cy

10IH1308 Unit 1 Tephra

		Unit 1		Unit 1		Unit 1		Unit 1		Unit 1		Unit 1		Unit 1		Unit 1		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	10IH1308 Unit 1	
Standards	SiO2	72.21	TiO2	0.42	Al2O3	14.22	Fe2O3	1.9	MgO	0.45	CaO	1.57	Na2O	3.46	K2O	2.62	Similarity Coefficient	
Mazama-O	70.90	98.19	0.42	100.00	13.90	97.75	2.12	89.62	0.36	80.00	1.50	95.54	4.53	76.38	2.76	94.93	**91.55**	Mazama-O
MSH-Ye	73.10	98.78	0.15	35.71	13.80	97.05	1.34	70.53	0.34	75.56	1.62	96.91	4.16	83.17	2.03	77.48	79.40	MSH-Ye
GP-B	72.30	99.88	0.25	59.52	12.20	85.79	1.16	61.05	0.24	53.33	1.24	78.98	2.79	80.64	2.86	91.61	76.35	GP-B
GP-G	72.90	99.05	0.20	47.62	12.10	85.09	0.98	51.58	0.19	42.22	1.05	66.88	3.59	96.38	3.30	79.39	71.03	GP-G
MSH-So	74.00	97.58	0.15	35.71	13.00	91.42	1.30	68.42	0.27	60.00	1.38	87.90	3.80	91.05	2.20	83.97	77.01	MSH-So
MSH-Sg	72.60	99.46	0.14	33.33	13.30	93.53	1.40	73.68	0.32	71.11	1.52	96.82	3.90	88.72	2.10	80.15	79.60	MSH-Sg
MSH-Jy	74.40	97.06	0.17	40.48	13.10	92.12	1.31	68.95	0.26	57.78	1.36	86.62	4.33	79.91	2.26	86.26	76.15	MSH-Jy
MSH-Mm	76.88	93.93	0.19	45.24	13.27	93.32	1.26	66.32	0.33	73.33	1.56	99.36	4.08	84.80	2.38	90.84	80.89	MSH-Mm
MSH-Cw	76.81	94.01	0.12	28.57	14.03	98.66	0.91	47.89	0.27	60.00	1.66	94.58	1.66	47.98	2.24	85.50	69.65	MSH-Cw
MSH-Cy	76.15	94.83	0.12	28.57	14.05	98.80	1.03	54.21	0.3	66.67	1.62	96.91	4.32	80.09	2.36	90.08	76.27	MSH-Cy

10IH395 Unit B Tephra

		Unit B		Unit B		Unit B		Unit B		Unit B		Unit B		Unit B		Unit B		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	10IH395 Unit B	
Standards	SiO2	72.12	TiO2	0.43	Al2O3	14.4	Fe2O3	1.87	MgO	0.44	CaO	1.58	Na2O	3.71	K2O	2.61	Similarity Coefficient	
Mazama-O	70.90	98.31	0.42	97.67	13.90	96.53	2.12	88.21	0.36	81.82	1.50	94.94	4.53	81.90	2.76	94.57	91.74	Mazama-O
MSH-Ye	73.10	98.66	0.15	34.88	13.80	95.83	1.34	71.66	0.34	77.27	1.62	97.53	4.16	89.18	2.03	77.78	80.35	MSH-Ye
GP-B	72.30	99.75	0.25	58.14	12.20	84.72	1.16	62.03	0.24	54.55	1.24	78.48	2.79	75.20	2.86	91.26	75.52	GP-B
GP-G	72.90	98.93	0.20	46.51	12.10	84.03	0.98	52.41	0.19	43.18	1.05	66.46	3.59	96.77	3.30	79.09	70.92	GP-G
MSH-So	74.00	97.46	0.15	34.88	13.00	90.28	1.30	69.52	0.27	61.36	1.38	87.34	3.80	97.63	2.20	84.29	77.85	MSH-So
MSH-Sg	72.60	99.34	0.14	32.56	13.30	92.36	1.40	74.87	0.32	72.73	1.52	96.20	3.90	95.13	2.10	80.46	80.46	MSH-Sg
MSH-Jy	74.40	96.94	0.17	39.53	13.10	90.97	1.31	70.05	0.26	59.09	1.36	86.08	4.33	85.68	2.26	86.59	76.87	MSH-Jy
MSH-Mm	76.88	93.81	0.19	44.19	13.27	92.15	1.26	67.38	0.33	75.00	1.56	98.73	4.08	90.93	2.38	91.19	81.67	MSH-Mm
MSH-Cw	76.81	93.89	0.12	27.91	14.03	97.43	0.91	48.66	0.27	61.36	1.66	95.18	1.66	44.74	2.24	85.82	69.38	MSH-Cw
MSH-Cy	76.15	94.71	0.12	27.91	14.05	97.57	1.03	55.08	0.3	68.18	1.62	97.53	4.32	85.88	2.36	90.42	77.16	MSH-Cy

SR-26-3 Unit 10-1 Tephra

		SR-26-3		SR-26-3		SR-26-3		SR-26-3		SR-26-3		SR-26-3		SR-26-3		SR-26-3		
Standards	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-26-3 Unit 10-1	
	SiO2	68.98	TiO2	0.65	Al2O3	14.82	Fe2O3	2.58	MgO	0.68	CaO	2.44	Na2O	3.85	K2O	2.92	Similarity Coefficient	
Mazama-O	70.90	97.29	0.42	64.62	13.90	93.79	2.12	82.17	0.36	52.94	1.50	61.48	4.53	84.99	2.76	94.52	78.97	Mazama-O
GP-B	72.30	95.41	0.25	38.46	12.20	82.32	1.16	44.96	0.24	35.29	1.24	50.82	2.79	72.47	2.86	97.95	64.71	GP-B
GP-G	72.90	94.62	0.20	30.77	12.10	81.65	0.98	37.98	0.19	27.94	1.05	43.03	3.59	93.25	3.30	88.48	62.22	GP-G
MSH-So	74.00	93.22	0.15	23.08	13.00	87.72	1.30	50.39	0.27	39.71	1.38	56.56	3.80	98.70	2.20	75.34	65.59	MSH-So
MSH-Sg	72.60	95.01	0.14	21.54	13.30	89.74	1.40	54.26	0.32	47.06	1.52	62.30	3.90	98.72	2.10	71.92	67.57	MSH-Sg
MSH-Jy	74.40	92.72	0.17	26.15	13.10	88.39	1.31	50.78	0.26	38.24	1.36	55.74	4.33	88.91	2.26	77.40	64.79	MSH-Jy
MSH-Mm	76.88	89.72	0.19	29.23	13.27	89.54	1.26	48.84	0.33	48.53	1.56	63.93	4.08	105.97	2.38	81.51	69.66	MSH-Mm
MSH-Cw	76.81	89.81	0.12	18.46	14.03	94.67	0.91	35.27	0.27	39.71	1.66	68.03	1.66	43.12	2.24	76.71	58.22	MSH-Cw
MSH-Cy	76.15	90.58	0.12	18.46	14.05	94.80	1.03	39.92	0.3	44.12	1.62	66.39	4.32	89.12	2.36	80.82	65.53	MSH-Cy

SR-26-4B Tephra

		SR-26-4B		SR-26-4B		SR-26-4B		SR-26-4B		SR-26-4B		SR-26-4B		SR-26-4B		SR-26-4B		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-26-4B	
Standards	SiO2	73.53	TiO2	0.09	Al2O3	13.23	Fe2O3	0.85	MgO	0.23	CaO	1.61	Na2O	4.48	K2O	2.36	Similarity	Coefficient
Mazama-O	70.90	96.42	0.42	21.43	13.90	95.18	2.12	40.09	0.36	63.89	1.50	93.17	4.53	98.90	2.76	85.51	74.32	Mazama-O
GP-B	72.30	98.33	0.25	36.00	12.20	92.21	1.16	73.28	0.24	95.83	1.24	77.02	2.79	62.28	2.86	82.52	77.18	GP-B
GP-G	72.90	99.14	0.20	45.00	12.10	91.46	0.98	86.73	0.19	82.61	1.05	65.22	3.59	80.13	3.30	71.52	77.73	GP-G
MSH-So	74.00	99.36	0.15	60.00	13.00	98.26	1.30	65.38	0.27	85.19	1.38	85.71	3.80	84.82	2.20	93.22	83.99	MSH-So
MSH-Sg	72.60	98.74	0.14	64.29	13.30	99.47	1.40	60.71	0.32	71.88	1.52	94.41	3.90	87.05	2.10	88.98	83.19	MSH-Sg
MSH-Jy	74.40	98.83	0.17	52.94	13.10	99.02	1.31	64.89	0.26	88.46	1.36	84.47	4.33	96.65	2.26	95.76	85.13	MSH-Jy
MSH-Mm	76.88	95.64	0.19	47.37	13.27	99.70	1.26	67.46	0.33	69.70	1.56	96.89	4.08	91.07	2.38	99.16	83.37	MSH-Mm
MSH-Cw	76.81	95.73	0.12	75.00	14.03	94.30	0.91	93.41	0.27	85.19	1.66	96.99	4.32	96.43	2.24	94.92	**91.49**	MSH-Cw
MSH-Cy	76.15	96.56	0.12	75.00	14.05	94.16	1.03	82.52	0.3	76.67	1.62	99.38	4.32	96.43	2.36	100.00	**90.09**	MSH-Cy
MSH-C (J.Davis 1985)	72.84	99.06	0.11	81.82	14	94.50	1.03	82.52	0.24	95.83	1.5	93.17	4.1	91.52	2.5	94.40	**91.60**	MSH-C
MSH So (Mullx et al.)	72.8	99.01	0.17	52.94	12.3	92.97	1.27	66.93	0.28	82.14	1.33	82.61	4.21	93.97	2.2	93.22	82.97	MSH So

SR-26-5 Tephra

		SR-26-5		SR-26-5		SR-26-5		SR-26-5		SR-26-5		SR-26-5		SR-26-5		SR-26-5		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-26-5	
Standards	SiO2	74.48	TiO2	0.21	Al2O3	12.18	Fe2O3	1.08	MgO	0.22	CaO	1.2	Na2O	4.4	K2O	3.17	Similarity	Coefficient
Mazama-O	70.90	95.19	0.42	50.00	13.90	87.63	2.12	50.94	0.36	61.11	1.50	80.00	4.53	97.13	2.76	87.07	76.13	Mazama-O
GP-B	72.30	97.07	0.25	84.00	12.20	99.84	1.16	93.10	0.24	91.67	1.24	96.77	2.79	63.41	2.86	90.22	**89.51**	GP-B
GP-G	72.90	97.88	0.20	95.24	12.10	99.34	0.98	90.74	0.19	86.36	1.05	87.50	3.59	81.59	3.30	96.06	**91.84**	GP-G
MSH-So	74.00	99.36	0.15	71.43	13.00	93.69	1.30	83.08	0.27	81.48	1.38	86.96	3.80	86.36	2.20	69.40	83.97	MSH-So
MSH-Sg	72.60	97.48	0.14	66.67	13.30	91.58	1.40	77.14	0.32	68.75	1.52	78.95	3.90	88.64	2.10	66.25	79.43	MSH-Sg
MSH-Jy	74.40	99.89	0.17	80.95	13.10	92.98	1.31	82.44	0.26	84.62	1.36	88.24	4.33	98.41	2.26	71.29	87.35	MSH-Jy
MSH-Mm	76.88	96.88	0.19	90.48	13.27	91.79	1.26	85.71	0.33	66.67	1.56	76.92	4.08	92.73	2.38	75.08	84.53	MSH-Mm
MSH-Cw	76.81	96.97	0.12	57.14	14.03	86.81	0.91	84.26	0.27	81.48	1.66	72.29	1.66	37.73	2.24	70.66	73.42	MSH-Cw
MSH-Cy	76.15	97.81	0.12	57.14	14.05	86.69	1.03	95.37	0.3	73.33	1.62	74.07	4.32	98.18	2.36	74.45	82.13	MSH-Cy

SR-40-1 Tephra

		SR-40-1		SR-40-1		SR-40-1		SR-40-1		SR-40-1		SR-40-1		SR-40-1		SR-40-1		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-40-1	
Standards	SiO2	71.38	TiO2	0.13	Al2O3	13.39	Fe2O3	1.73	MgO	0.11	CaO	0.75	Na2O	5.46	K2O	3.21	Similarity Coefficient	
Mazama-O	70.90	99.33	0.42	30.95	13.90	96.33	2.12	81.60	0.36	30.56	1.50	50.00	4.53	82.97	2.76	85.98	69.71	Mazama-O
GP-B	72.30	98.73	0.25	52.00	12.20	91.11	1.16	67.05	0.24	45.83	1.24	60.48	2.79	51.10	2.86	89.10	69.43	GP-B
GP-G	72.90	97.91	0.20	65.00	12.10	90.37	0.98	56.65	0.19	57.89	1.05	71.43	3.59	65.75	3.30	97.27	75.28	GP-G
MSH-So	74.00	96.46	0.15	86.67	13.00	97.09	1.30	75.14	0.27	40.74	1.38	54.35	3.80	69.60	2.20	68.54	73.57	MSH-So
MSH-Sg	72.60	98.32	0.14	92.86	13.30	99.33	1.40	80.92	0.32	34.38	1.52	49.34	3.90	71.43	2.10	65.42	74.00	MSH-Sg
MSH-Jy	74.40	95.94	0.17	76.47	13.10	97.83	1.31	75.72	0.26	42.31	1.36	55.15	4.33	79.30	2.26	70.40	74.14	MSH-Jy
MSH-Mm	76.88	92.85	0.19	68.42	13.27	99.10	1.26	72.83	0.33	33.33	1.56	48.08	4.08	74.73	2.38	74.14	70.44	MSH-Mm
MSH-Cw	76.81	92.93	0.12	92.31	14.03	95.44	0.91	52.60	0.27	40.74	1.66	45.18	1.66	30.40	2.24	69.78	64.92	MSH-Cw
MSH-Cy	76.15	93.74	0.12	92.31	14.05	95.30	1.03	59.54	0.3	36.67	1.62	46.30	4.32	79.12	2.36	73.52	72.06	MSH-Cy
SR-26-4/10-1	68.98	96.64	0.65	20.00	14.82	90.35	2.58	67.05	0.68	16.18	2.44	30.74	3.85	70.51	2.92	90.97	60.30	SR-26-4/10-1

SR-40 Tephra

		SR-40		SR-40		SR-40		SR-40		SR-40		SR-40		SR-40		SR-40		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-40	
Standards	SiO2	71.79	TiO2	0.16	Al2O3	13.43	Fe2O3	1.77	MgO	0.12	CaO	0.74	Na2O	4.18	K2O	3.09	Similarity Coefficient	
Mazama-O	70.90	98.76	0.42	38.10	13.90	96.62	2.12	83.49	0.36	33.33	1.50	49.33	4.53	92.27	2.76	89.32	72.65	Mazama-O
GP-B	72.30	99.29	0.25	64.00	12.20	90.84	1.16	65.54	0.24	50.00	1.24	59.68	2.79	66.75	2.86	92.56	73.58	GP-B
GP-G	72.90	98.48	0.20	80.00	12.10	90.10	0.98	55.37	0.19	63.16	1.05	70.48	3.59	85.89	3.30	93.64	79.64	GP-G
MSH-So	74.00	97.01	0.15	93.75	13.00	96.80	1.30	73.45	0.27	44.44	1.38	53.62	3.80	90.91	2.20	71.20	77.65	MSH-So
MSH-Sg	72.60	98.88	0.14	87.50	13.30	99.03	1.40	79.10	0.32	37.50	1.52	48.68	3.90	93.30	2.10	67.96	76.49	MSH-Sg
MSH-Jy	74.40	96.49	0.17	94.12	13.10	97.54	1.31	74.01	0.26	46.15	1.36	54.41	4.33	96.54	2.26	73.14	79.05	MSH-Jy
MSH-Mm	76.88	107.09	0.19	118.75	13.27	98.81	1.26	71.19	0.33	36.36	1.56	47.44	4.08	97.61	2.38	77.02	81.78	MSH-Mm
MSH-Cw	76.81	106.99	0.12	75.00	14.03	104.47	0.91	51.41	0.27	44.44	1.66	44.58	1.66	39.71	2.24	72.49	67.39	MSH-Cw
MSH-Cy	76.15	94.27	0.12	75.00	14.05	104.62	1.03	58.19	0.3	40.00	1.62	45.68	4.32	103.35	2.36	76.38	74.69	MSH-Cy
SR-26-3/10-1	68.98	96.09	0.65	24.62	14.82	90.62	2.58	68.60	0.68	17.65	2.44	30.33	3.85	92.11	2.92	94.50	64.31	SR-26-4/10-1
SR-40-1	71.38	99.43	0.13	81.25	13.39	99.70	1.73	97.74	0.11	91.67	0.75	98.67	5.46	76.56	3.21	96.26	**92.66**	SR-40-1

SR-42 Tephra		SR-42		SR-42		SR-42		SR-42		SR-42		SR-42		SR-42		SR-42		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-42	
Standards	SiO2	72.57	TiO2	0.46	Al2O3	14.46	Fe2O3	1.96	MgO	0.44	CaO	1.64	Na2O	4.42	K2O	2.71	Similarity Coefficient	
Mazama-O	70.90	97.70	0.42	91.30	13.90	96.13	2.12	92.45	0.36	81.82	1.50	91.46	4.53	97.57	2.76	98.19	**93.33**	Mazama-O
GP-B	72.30	99.63	0.25	54.35	12.20	84.37	1.16	59.18	0.24	54.55	1.24	75.61	2.79	63.12	2.86	94.76	73.20	GP-B
GP-G	72.90	99.55	0.20	43.48	12.10	83.68	0.98	50.00	0.19	43.18	1.05	64.02	3.59	81.22	3.30	82.12	68.41	GP-G
MSH-So	74.00	98.07	0.15	32.61	13.00	89.90	1.30	66.33	0.27	61.36	1.38	84.15	3.80	85.97	2.20	81.18	74.95	MSH-So
MSH-Sg	72.60	99.96	0.14	30.43	13.30	91.98	1.40	71.43	0.32	72.73	1.52	92.68	3.90	88.24	2.10	77.49	78.12	MSH-Sg
MSH-Jy	74.40	97.54	0.17	36.96	13.10	90.59	1.31	66.84	0.26	59.09	1.36	82.93	4.33	97.96	2.26	83.39	76.91	MSH-Jy
MSH-Mm	76.88	94.39	0.19	41.30	13.27	91.77	1.26	64.29	0.33	75.00	1.56	95.12	4.08	92.31	2.38	87.82	80.25	MSH-Mm
MSH-Cw	76.81	94.48	0.12	26.09	14.03	97.03	0.91	46.43	0.27	61.36	1.66	98.80	1.66	37.56	2.24	82.66	68.05	MSH-Cw
MSH-Cy	76.15	95.30	0.12	26.09	14.05	97.16	1.03	52.55	0.3	68.18	1.62	98.78	4.32	97.74	2.36	87.08	77.86	MSH-Cy
SR-26-3/10-1	68.98	95.05	0.65	70.77	14.82	97.57	2.58	75.97	0.68	64.71	2.44	67.21	3.85	87.10	2.92	107.75	83.27	SR-26-4/10-1
SR-40-1	71.38	98.36	0.13	28.26	13.39	92.60	1.73	88.27	0.11	25.00	0.75	45.73	5.46	80.95	3.21	84.42	67.95	SR-40-1

SR-43 Tephra		SR-43		SR-43		SR-43		SR-43		SR-43		SR-43		SR-43		SR-43		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-43	
Standards	SiO2	67.45	TiO2	0.18	Al2O3	11.15	Fe2O3	0.98	MgO	0.23	CaO	1.17	Na2O	2.94	K2O	2.76	Similarity Coefficient	
Mazama-O	70.90	95.13	0.42	42.86	13.90	80.22	2.12	46.23	0.36	63.89	1.50	78.00	4.53	64.90	2.76	100.00	71.40	Mazama-O
GP-B	72.30	93.29	0.25	72.00	12.20	91.39	1.16	84.48	0.24	95.83	1.24	94.35	2.79	94.90	2.86	96.50	**90.34**	GP-B
GP-G	72.90	92.52	0.20	90.00	12.10	92.15	0.98	100.00	0.19	82.61	1.05	89.74	3.59	81.89	3.30	83.64	89.07	GP-G
MSH-So	74.00	91.15	0.15	83.33	13.00	85.77	1.30	75.38	0.27	85.19	1.38	84.78	3.80	77.37	2.20	79.71	82.84	MSH-So
MSH-Sg	72.60	92.91	0.14	77.78	13.30	83.83	1.40	70.00	0.32	71.88	1.52	76.97	3.90	75.38	2.10	76.09	78.10	MSH-Sg
MSH-Jy	74.40	90.66	0.17	94.44	13.10	85.11	1.31	74.81	0.26	88.46	1.36	86.03	4.33	67.90	2.26	81.88	83.66	MSH-Jy
MSH-Mm	76.88	87.73	0.19	94.74	13.27	84.02	1.26	77.78	0.33	69.70	1.56	75.00	4.08	72.06	2.38	86.23	80.91	MSH-Mm
MSH-Cw	76.81	87.81	0.12	66.67	14.03	79.47	0.91	92.86	0.27	85.19	1.66	70.48	1.66	56.46	2.24	81.16	77.51	MSH-Cw
MSH-Cy	76.15	88.58	0.12	66.67	14.05	79.36	1.03	95.15	0.3	76.67	1.62	72.22	4.32	68.06	2.36	85.51	79.02	MSH-Cy
SR-26-3/10-1	68.98	97.78	0.65	27.69	14.82	75.24	2.58	37.98	0.68	33.82	2.44	47.95	3.85	76.36	2.92	94.52	61.42	SR-26-4/10-1
SR-40-1	71.38	94.49	0.13	72.22	13.39	83.27	1.73	56.65	0.11	47.83	0.75	64.10	5.46	53.85	3.21	85.98	69.80	SR-40-1

SR-43 Tephra		SR-43		SR-43		SR-43		SR-43		SR-43		SR-43		SR-43		SR-43		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-43	
Standards	SiO2	67.45	TiO2	0.18	Al2O3	11.15	Fe2O3	0.98	MgO	0.23	CaO	1.17	Na2O	2.94	K2O	2.76	Similarity Coefficient	
MA-79C138	73.10	92.28	0.41	44.79	14.30	78.00	2.30	42.65	0.45	50.71	1.63	71.56	4.20	70.00	3.30	83.53	66.69	MA-79C138
MA-79C196	72.20	93.43	0.46	39.92	14.30	78.00	2.40	40.87	0.53	43.05	1.84	63.39	4.20	70.00	3.10	88.91	64.70	MA-79C196
GP-B	71.30	94.61	0.21	87.45	12.20	91.42	1.20	81.74	0.28	81.49	1.28	91.12	3.00	98.00	2.70	97.96	**90.47**	GP-B
GP-G	71.90	93.82	0.18	98.02	12.10	92.18	1.10	89.17	0.25	91.27	1.12	96.02	2.80	95.24	2.90	95.05	**93.85**	GP-G
MSH-So	74.00	91.15	0.15	81.68	13.00	85.80	1.30	75.45	0.27	84.51	1.38	84.52	3.80	77.37	2.20	79.82	82.54	MSH-So
MSH-Sg	72.60	92.91	0.14	76.24	13.30	83.86	1.40	70.06	0.32	71.31	1.52	76.73	3.90	75.38	2.10	76.19	77.84	MSH-Sg
MSH-Jy	74.30	90.79	0.18	98.02	13.20	84.50	1.40	70.06	0.29	78.68	1.41	82.72	4.10	71.71	2.20	79.82	82.04	MSH-Jy
MSH-Jb	68.90	97.90	0.24	76.52	14.00	79.67	1.90	51.63	0.42	54.33	1.78	65.53	3.80	77.37	1.80	65.30	71.03	MSH-Jb
MSH-Mm	71.40	94.47	0.15	81.68	12.90	86.46	1.30	75.45	0.30	76.06	1.38	84.52	3.70	79.46	2.20	79.82	82.24	MSH-Mm
MSH-Mc	70.60	95.54	0.19	96.65	12.90	86.46	1.30	75.45	0.33	69.15	1.46	79.89	3.60	81.67	2.20	79.82	83.08	MSH-Mc
MSH-Cw	71.50	94.34	0.09	49.01	13.20	84.50	1.10	89.17	0.27	84.51	1.58	73.82	3.50	84.00	2.10	76.19	79.44	MSH-Cw
MSH-Cy	72.30	93.30	0.10	54.46	13.40	83.24	1.00	98.09	0.26	87.76	1.47	79.34	3.70	79.46	2.30	83.44	82.39	MSH-Cy
Bridge River	74.65	90.36	0.36	51.01	13.57	82.19	1.65	59.45	0.38	60.05	1.41	82.72	4.64	63.36	3.20	86.14	71.91	Bridge River
GP-B (Porter 1978)	72.30	93.30	0.25	73.45	12.20	91.42	1.16	84.56	0.24	95.08	1.24	94.06	2.79	94.90	2.86	96.38	**90.39**	GP-B
MSH So (Mullix et al.)	72.80	92.66	0.17	92.57	12.30	90.68	1.27	77.24	0.28	81.49	1.33	87.70	4.21	69.83	2.20	79.82	84.00	MSH So
MSH-Yn	74.81	90.17	0.17	92.57	14.38	77.56	1.36	72.13	0.55	41.49	1.89	61.71	4.63	63.50	2.11	76.55	71.96	MSH-Yn

SR-42 Tephra		SR-42		SR-42		SR-42		SR-42		SR-42		SR-42		SR-42		SR-42		
	STD	SiO2	STD	TiO2	STD	Al2O3	STD	Fe2O3	STD	MgO	STD	CaO	STD	Na2O	STD	K2O	SR-42	
Standards	SiO2	72.67	TiO2	0.45	Al2O3	14.35	Fe2O3	1.92	MgO	0.43	CaO	1.60	Na2O	4.34	K2O	2.75	Similarity Coefficient	
MA-79C138	73.10	99.42	0.41	91.83	14.30	99.68	2.30	83.48	0.45	95.33	1.63	98.31	4.20	96.69	3.30	83.36	**93.51**	MA-79C138
MA-79C196	72.20	99.35	0.46	97.07	14.30	99.68	2.40	80.00	0.53	80.94	1.84	87.09	4.20	96.69	3.10	88.74	**91.19**	MA-79C196
GP-B	71.30	98.11	0.21	47.03	12.20	85.04	1.20	62.50	0.28	65.27	1.28	79.88	3.00	69.06	2.70	98.15	75.63	GP-B
GP-G	71.90	98.93	0.18	40.31	12.10	84.35	1.10	57.29	0.25	58.28	1.12	69.89	2.80	64.46	2.90	94.86	71.05	GP-G
MSH-So	74.00	98.21	0.15	33.59	13.00	90.62	1.30	67.71	0.27	62.94	1.38	86.12	3.80	87.48	2.20	79.97	75.83	MSH-So
MSH-Sg	72.60	99.90	0.14	31.35	13.30	92.71	1.40	72.92	0.32	74.59	1.52	94.85	3.90	89.78	2.10	76.34	79.06	MSH-Sg
MSH-Jy	74.30	97.81	0.18	40.31	13.20	92.01	1.40	72.92	0.29	67.60	1.41	87.99	4.10	94.38	2.20	79.97	79.12	MSH-Jy
MSH-Jb	68.90	94.81	0.24	53.75	14.00	97.59	1.90	98.96	0.42	97.90	1.78	90.03	3.80	87.48	1.80	65.43	85.74	MSH-Jb
MSH-Mm	71.40	98.25	0.15	33.59	12.90	89.92	1.30	67.71	0.30	69.93	1.38	86.12	3.70	85.17	2.20	79.97	76.33	MSH-Mm
MSH-Mc	70.60	97.15	0.19	42.55	12.90	89.92	1.30	67.71	0.33	76.92	1.46	91.11	3.60	82.87	2.20	79.97	78.53	MSH-Mc
MSH-Cw	71.50	98.38	0.09	20.16	13.20	92.01	1.10	57.29	0.27	62.94	1.58	98.60	3.50	80.57	2.10	76.34	73.29	MSH-Cw
MSH-Cy	72.30	99.49	0.10	22.40	13.40	93.41	1.00	52.08	0.26	60.61	1.47	91.73	3.70	85.17	2.30	83.61	73.56	MSH-Cy
Bridge River	74.65	97.35	0.36	80.63	13.57	94.59	1.65	85.94	0.38	88.58	1.41	87.99	4.64	93.62	3.20	85.97	89.33	Bridge River
GP-B (Porter 1978)	72.30	99.49	0.25	55.99	12.20	85.04	1.16	60.42	0.24	55.94	1.24	77.38	2.79	64.23	2.86	96.19	74.33	GP-B
MSH So (Mullix et al.)	72.80	99.83	0.17	38.07	12.30	85.74	1.27	66.15	0.28	65.27	1.33	83.00	4.21	96.92	2.20	79.97	76.87	MSH So
MSH-Yn	74.81	97.14	0.17	38.07	14.38	99.76	1.36	70.83	0.55	78.00	1.89	84.79	4.63	93.82	2.11	76.70	79.89	MSH-Yn

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Map 1. Late Quaternary Surficial Geology Units and Predicted Association of Archaeological Components in the Lower Salmon River Canyon, Idaho, Between Hammer Creek and American Bar.

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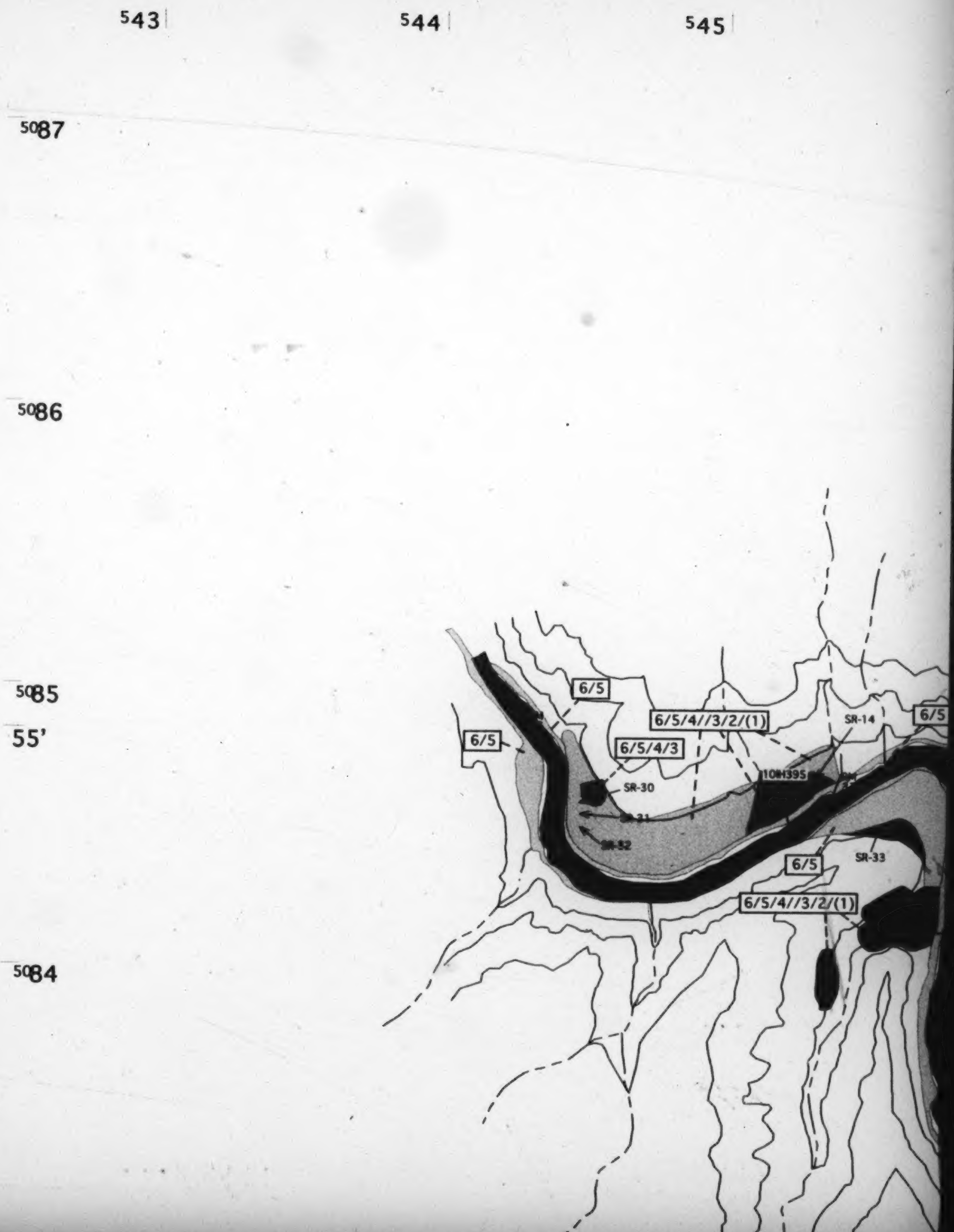
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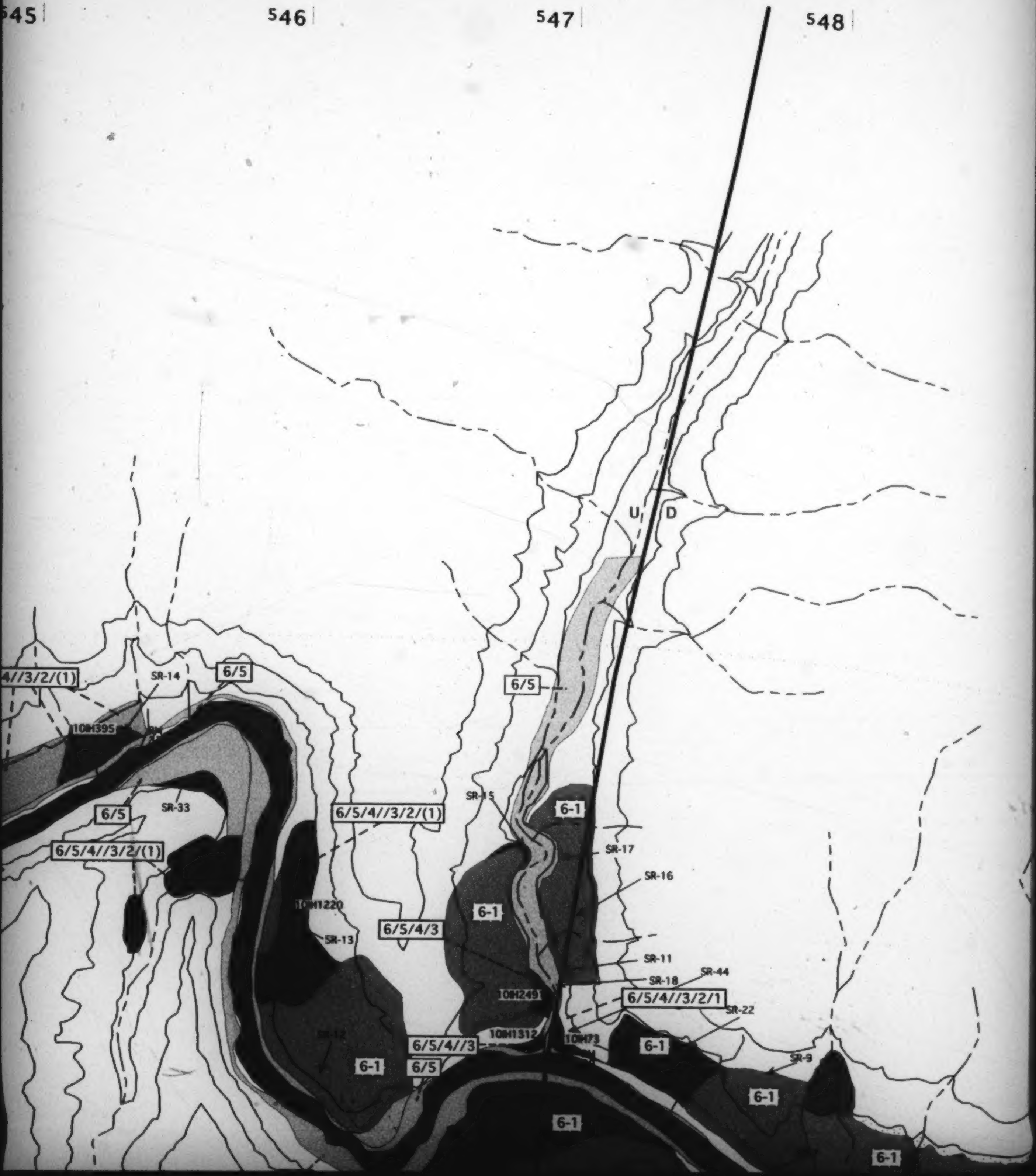545
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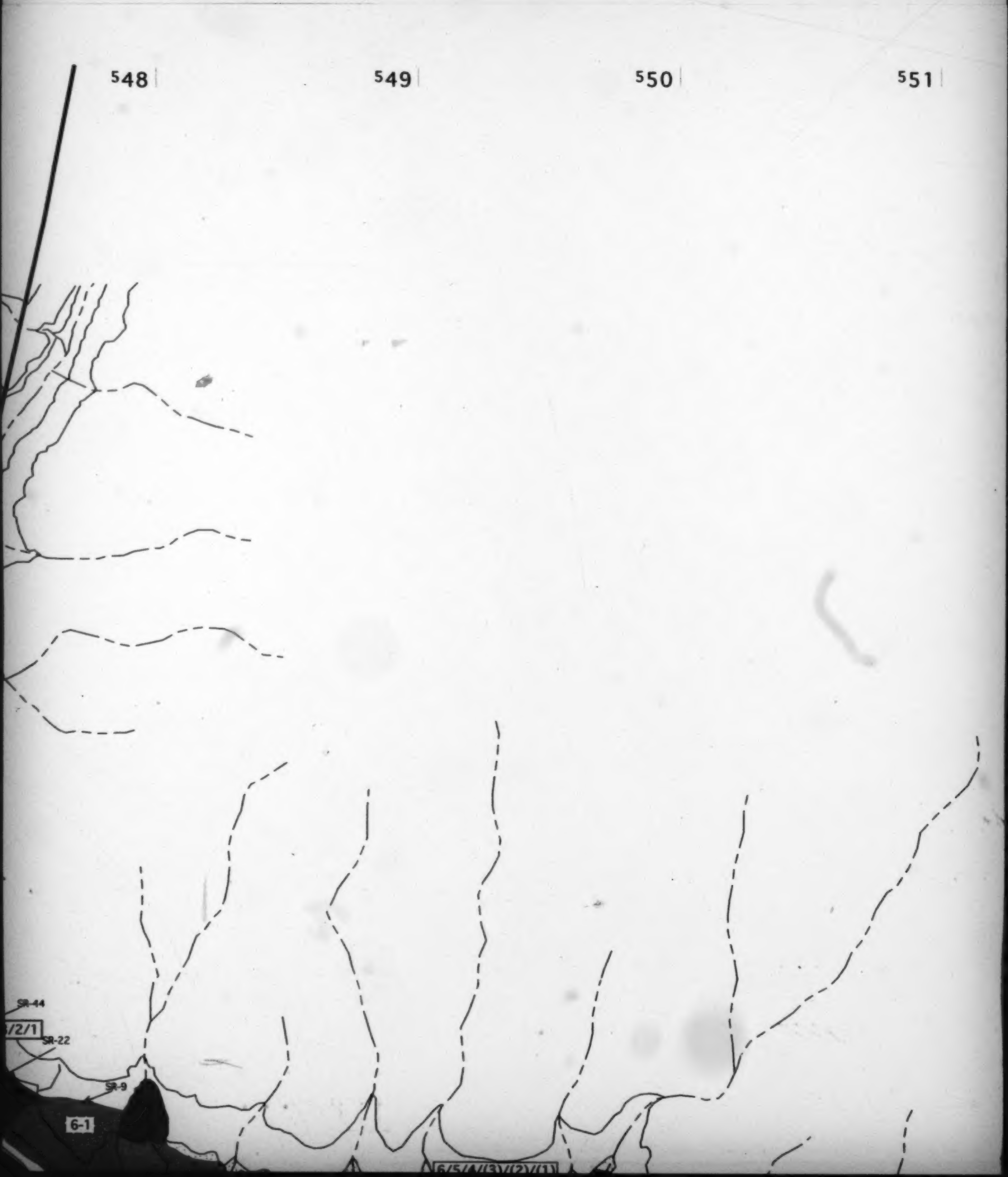
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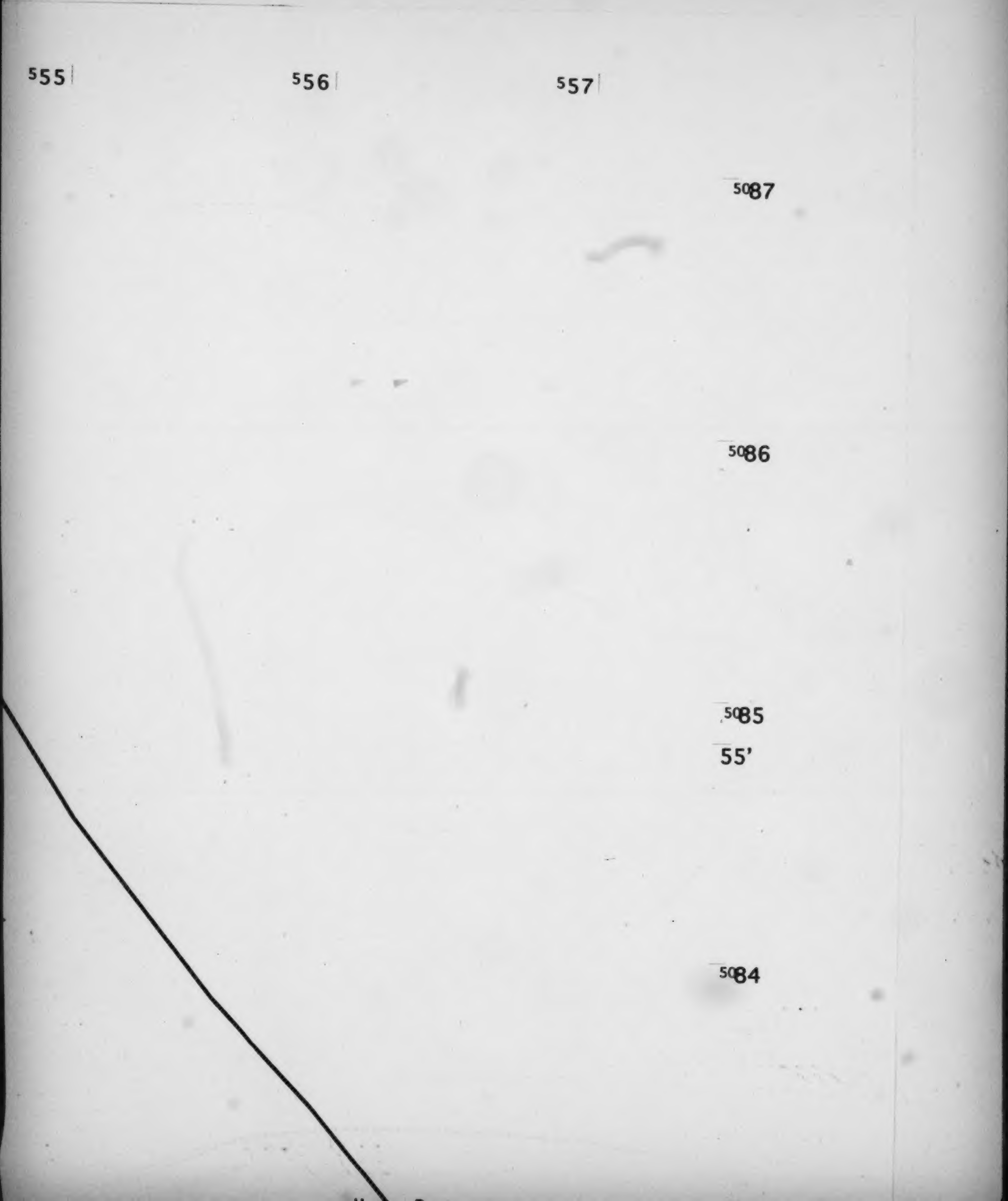
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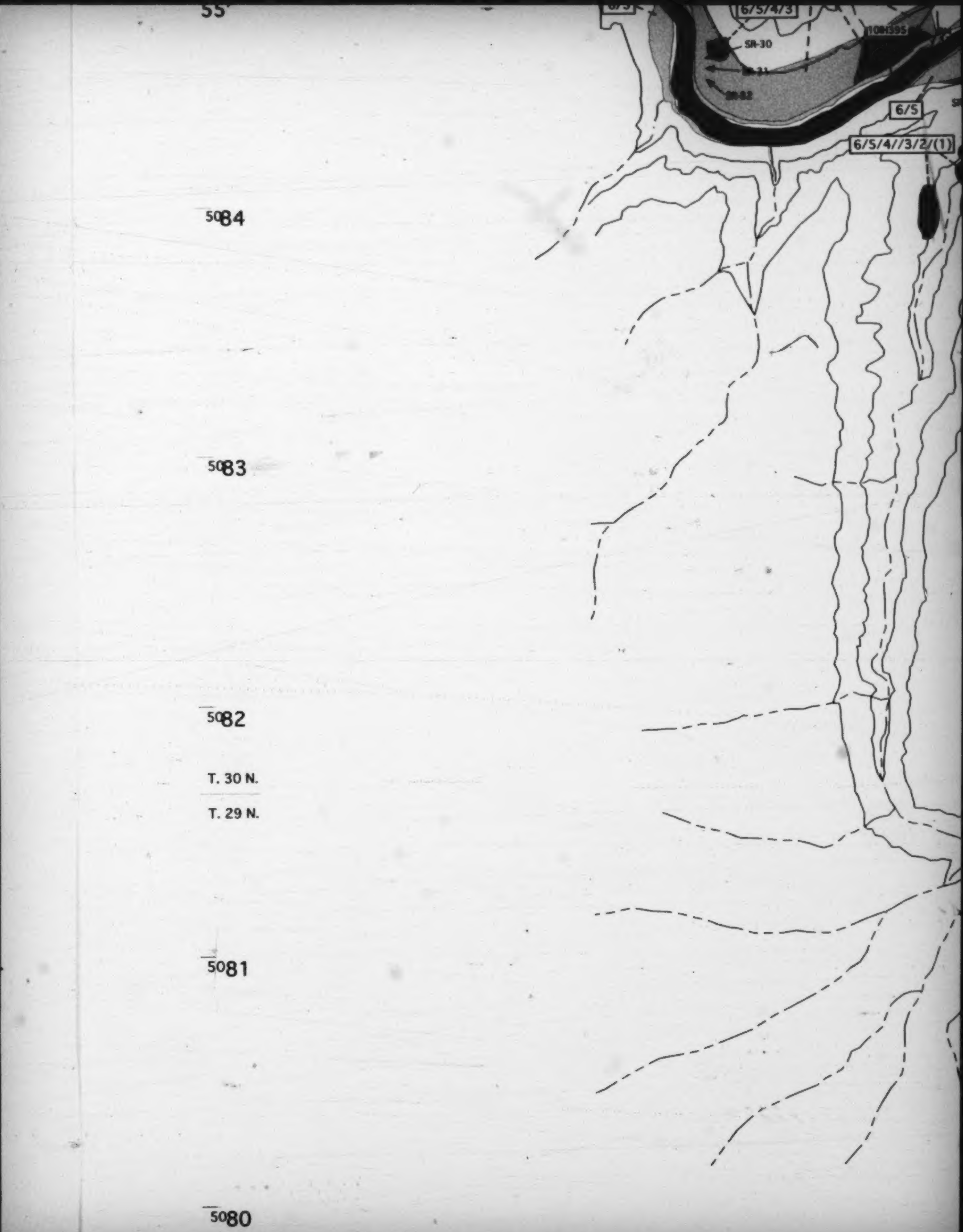
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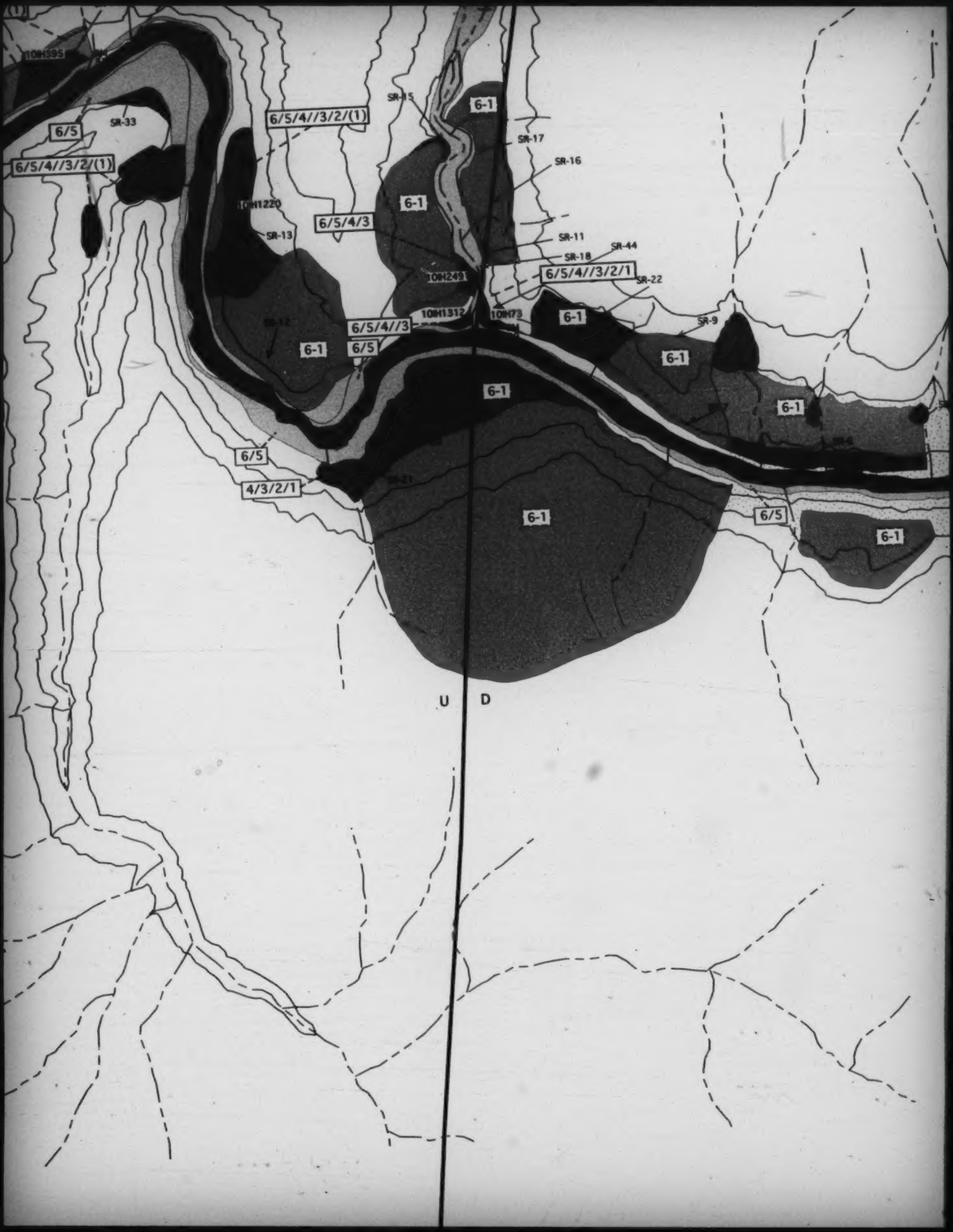
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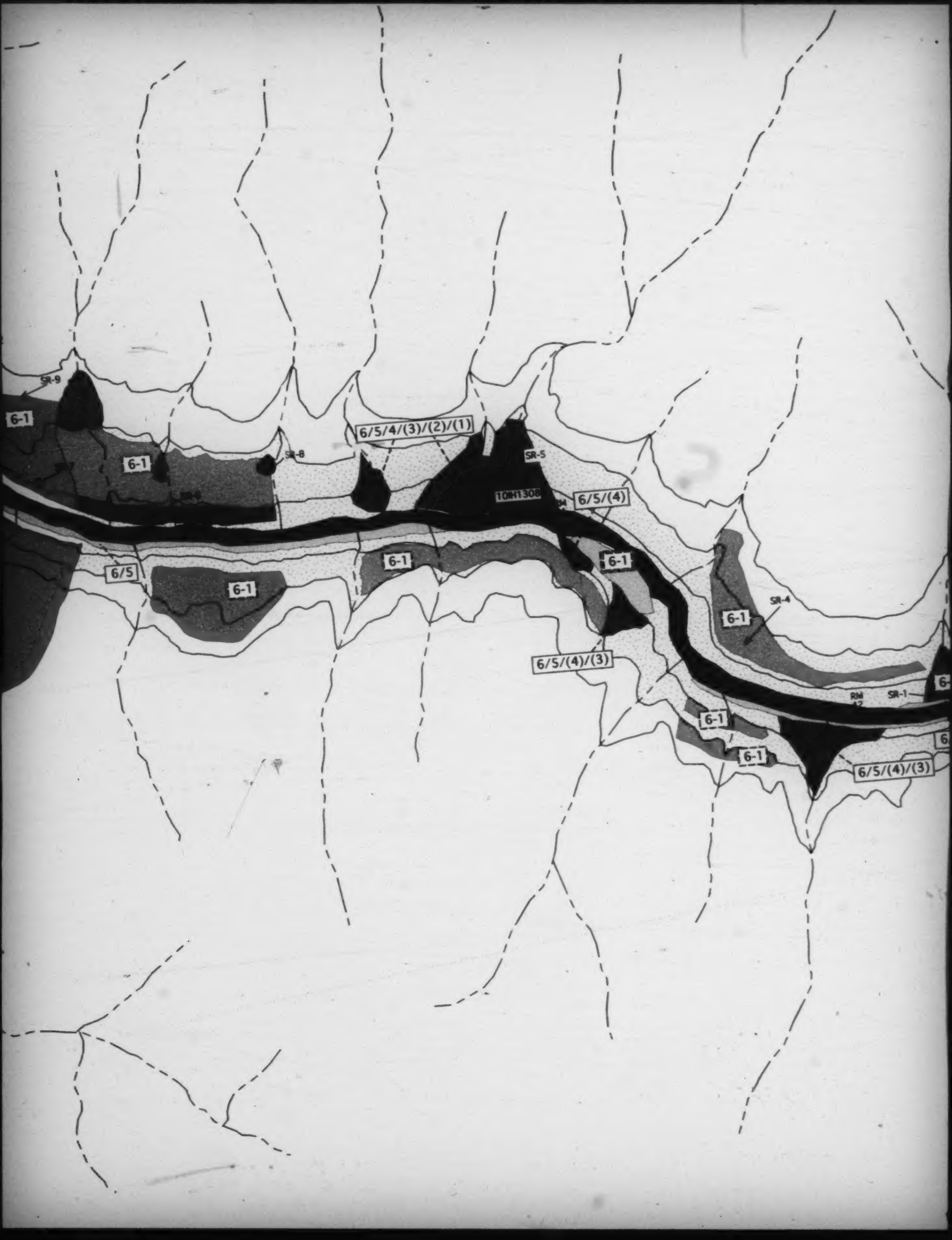
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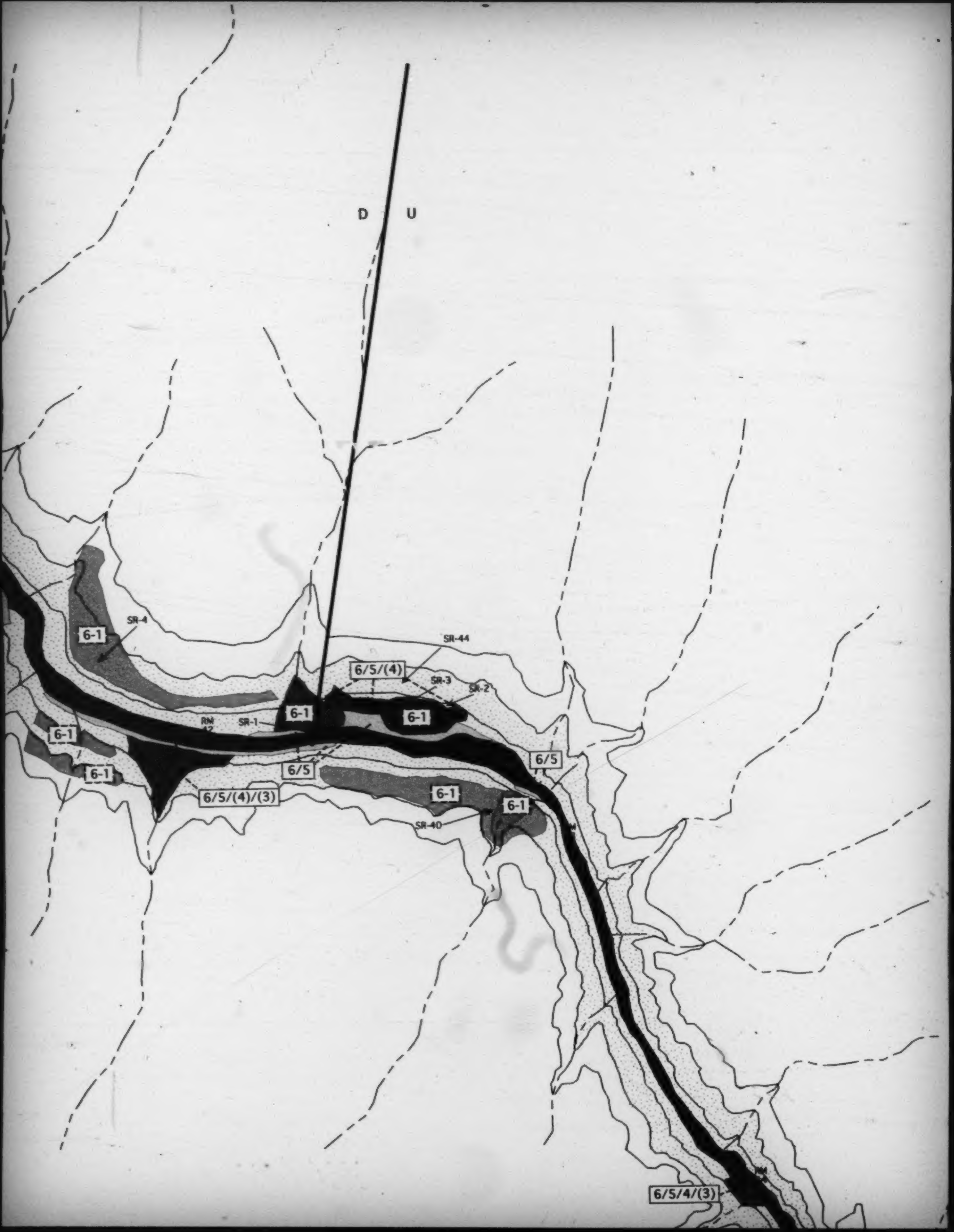
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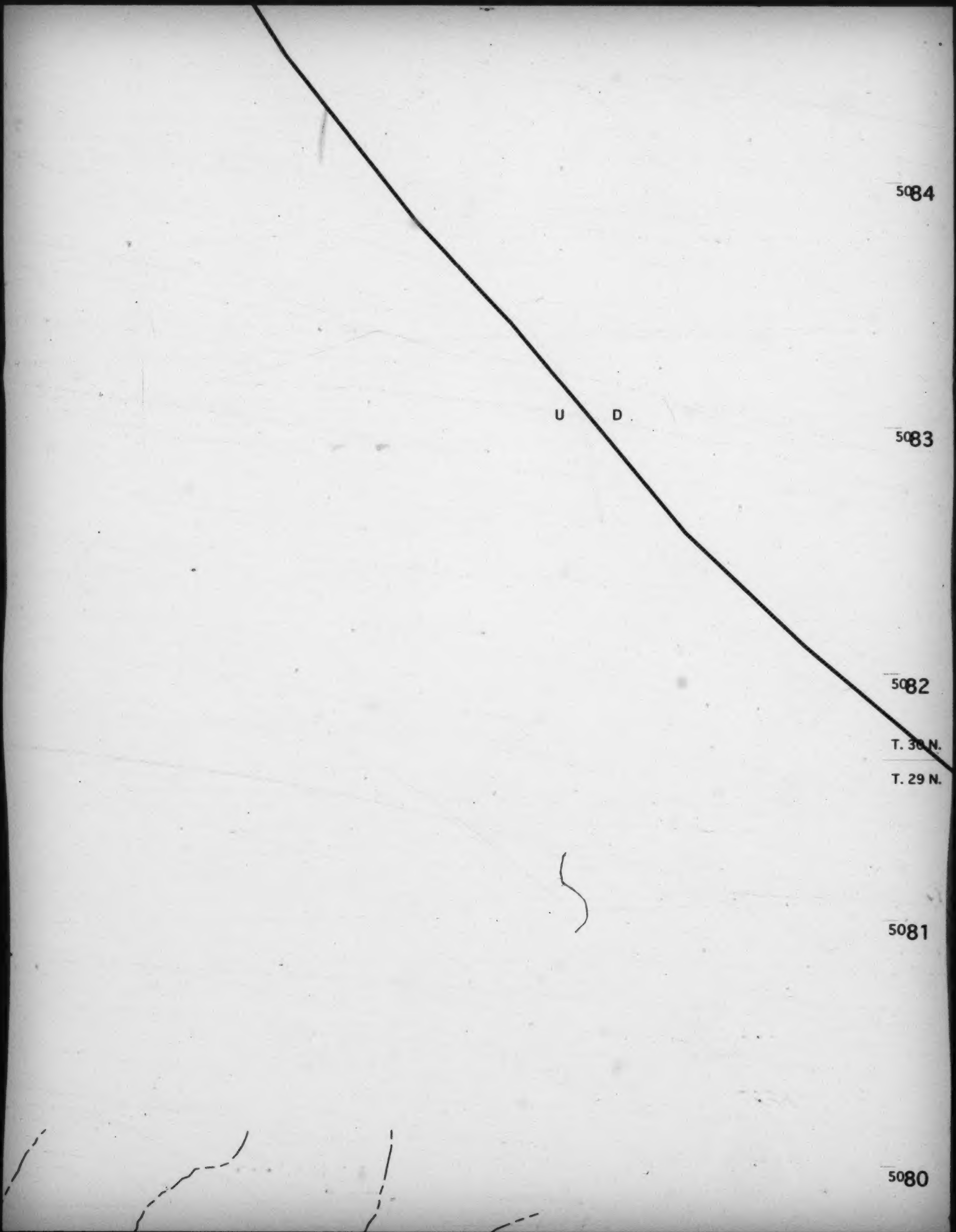
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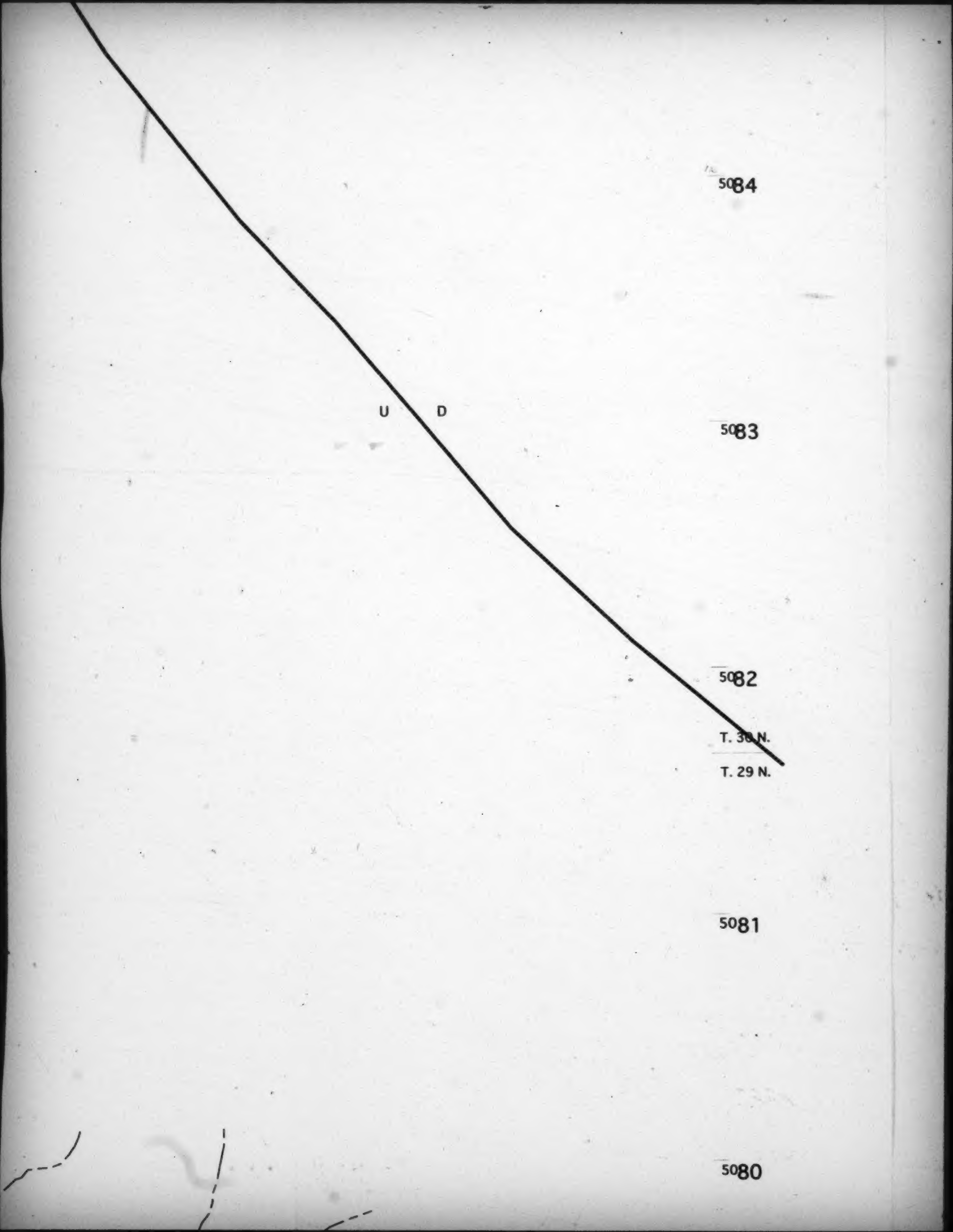
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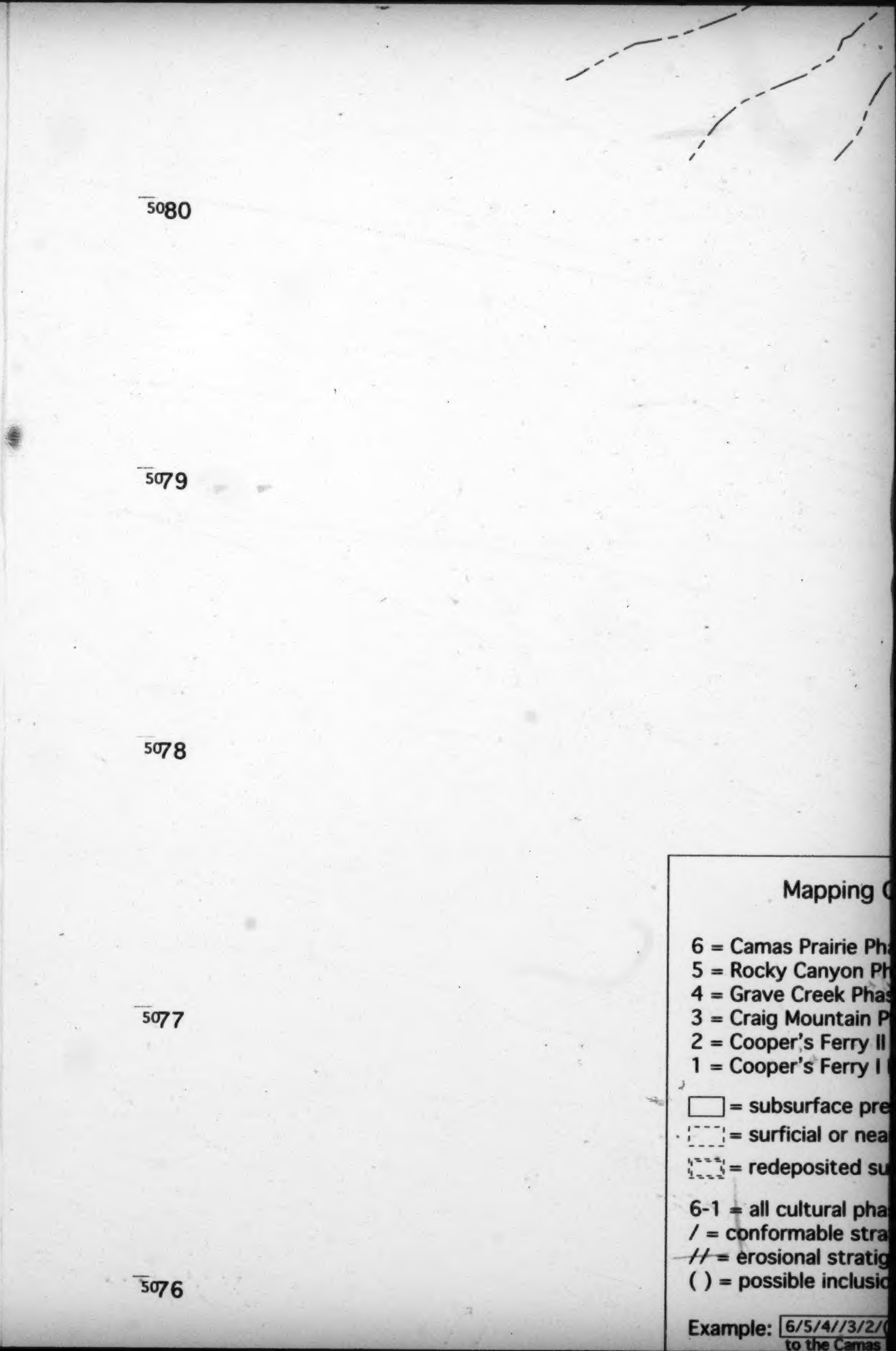
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Mapping C
6 = Camas Prairie Ph
5 = Rocky Canyon Ph
4 = Grave Creek Phas
3 = Craig Mountain P
2 = Cooper's Ferry II
1 = Cooper's Ferry I
= subsurface pre
= surficial or nea
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6-1 = all cultural pha
/ = conformable stra
// = erosional stratig
( ) = possible inclusio
Example: 6/5/4//3/2/(
to the Camas

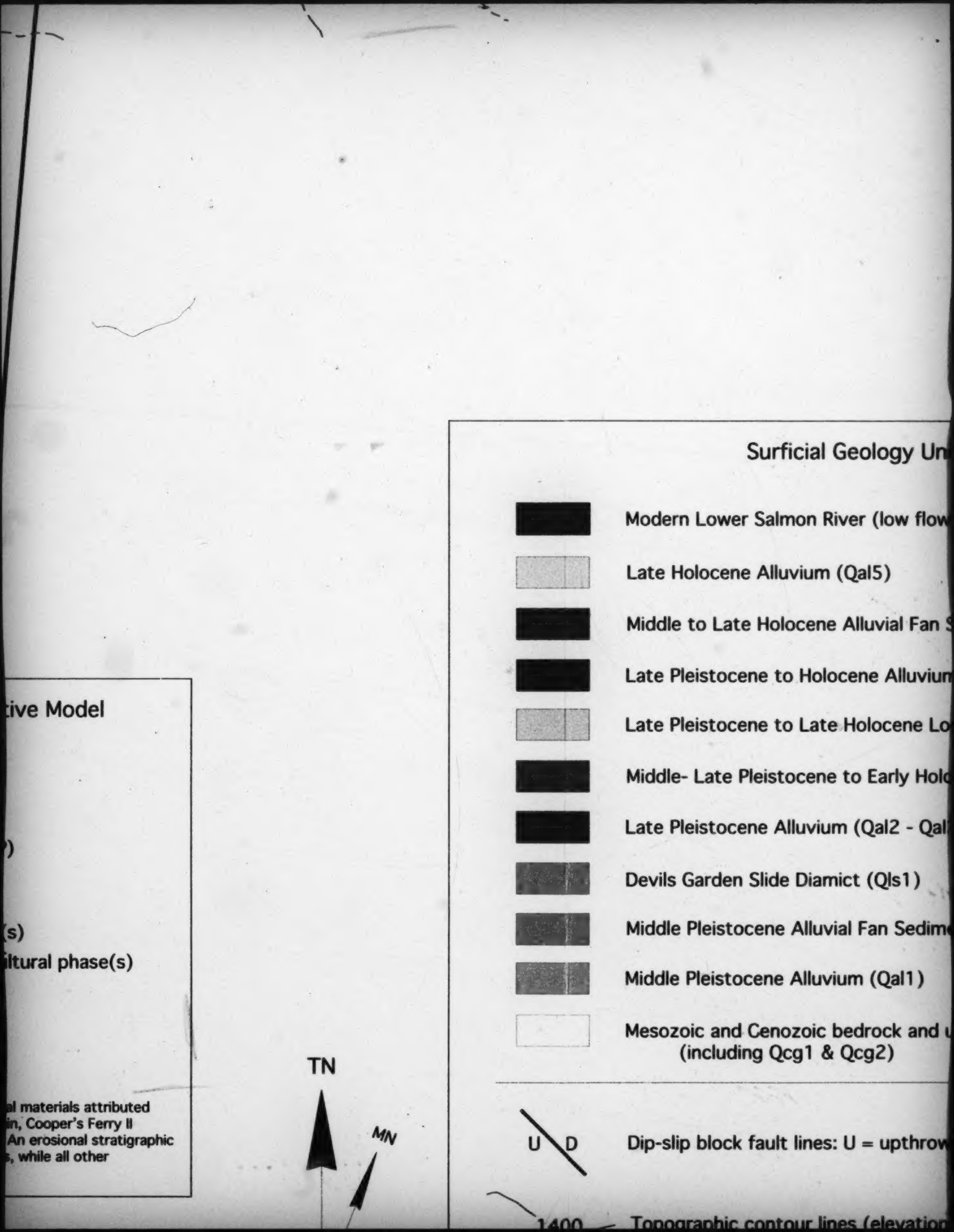
Mapping Codes for Archaeological Predictive Model

6 = Camas Prairie Phase (600 - 150 yr BP)
5 = Rocky Canyon Phase (2,100 - 600 yr BP)
4 = Grave Creek Phase (3,500 - 2,100 yr BP)
3 = Craig Mountain Phase (8,400 (?) - 3,500 yr BP)
2 = Cooper's Ferry II Phase (11,000 (?) - 8,400 (?) yr BP)
1 = Cooper's Ferry I Phase (11,500 - 11,000 (?) yr BP)

☐ = subsurface presence of cultural phase(s)
⬚ = surficial or near-surface presence of cultural phase(s)
⬚ = redeposited surficial or near-surface presence of cultural phase(s)

6-1 = all cultural phases
/ = conformable stratigraphic boundary
// = erosional stratigraphic boundary
( ) = possible inclusion of cultural phase

Example: 6/5/4//3/2/(1) = denotes a buried sequence of archaeological materials attributed to the Camas Prairie, Rocky Canyon, Grave Creek, Craig Mountain, Cooper's Ferry II phases with a possible inclusion of the Cooper's Ferry I phase. An erosional stratigraphic boundary separates the Grave Creek and Craig Mountain phases, while all other stratigraphic boundaries are conformable.



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Surficial Geology Un

■	Modern Lower Salmon River (low flow
▨	Late Holocene Alluvium (Qal5)
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■	Late Pleistocene to Holocene Alluviun
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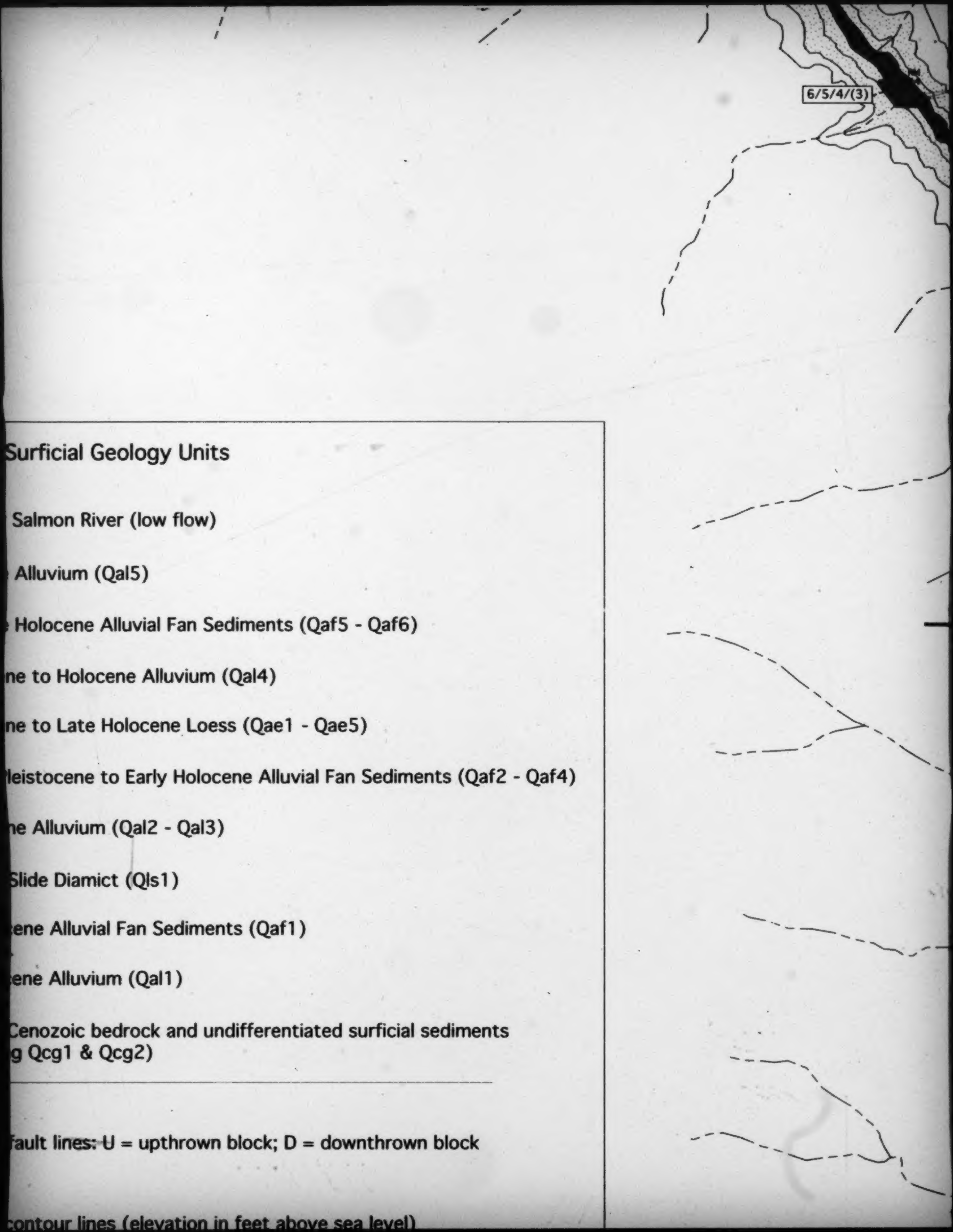
■	Middle- Late Pleistocene to Early Holo
■	Late Pleistocene Alluvium (Qal2 - Qal
▨	Devils Garden Slide Diamict (Qls1)
▨	Middle Pleistocene Alluvial Fan Sedim
▨	Middle Pleistocene Alluvium (Qal1)
□	Mesozoic and Cenozoic bedrock and u (including Qcg1 & Qcg2)

U D Dip-slip block fault lines: U = upthrow

1400 Topographic contour lines (elevation



Surficial Geology Units

Salmon River (low flow)

Alluvium (Qal5)

Holocene Alluvial Fan Sediments (Qaf5 - Qaf6)

ne to Holocene Alluvium (Qal4)

ne to Late Holocene Loess (Qae1 - Qae5)

leistocene to Early Holocene Alluvial Fan Sediments (Qaf2 - Qaf4)

ne Alluvium (Qal2 - Qal3)

Slide Diamict (Qls1)

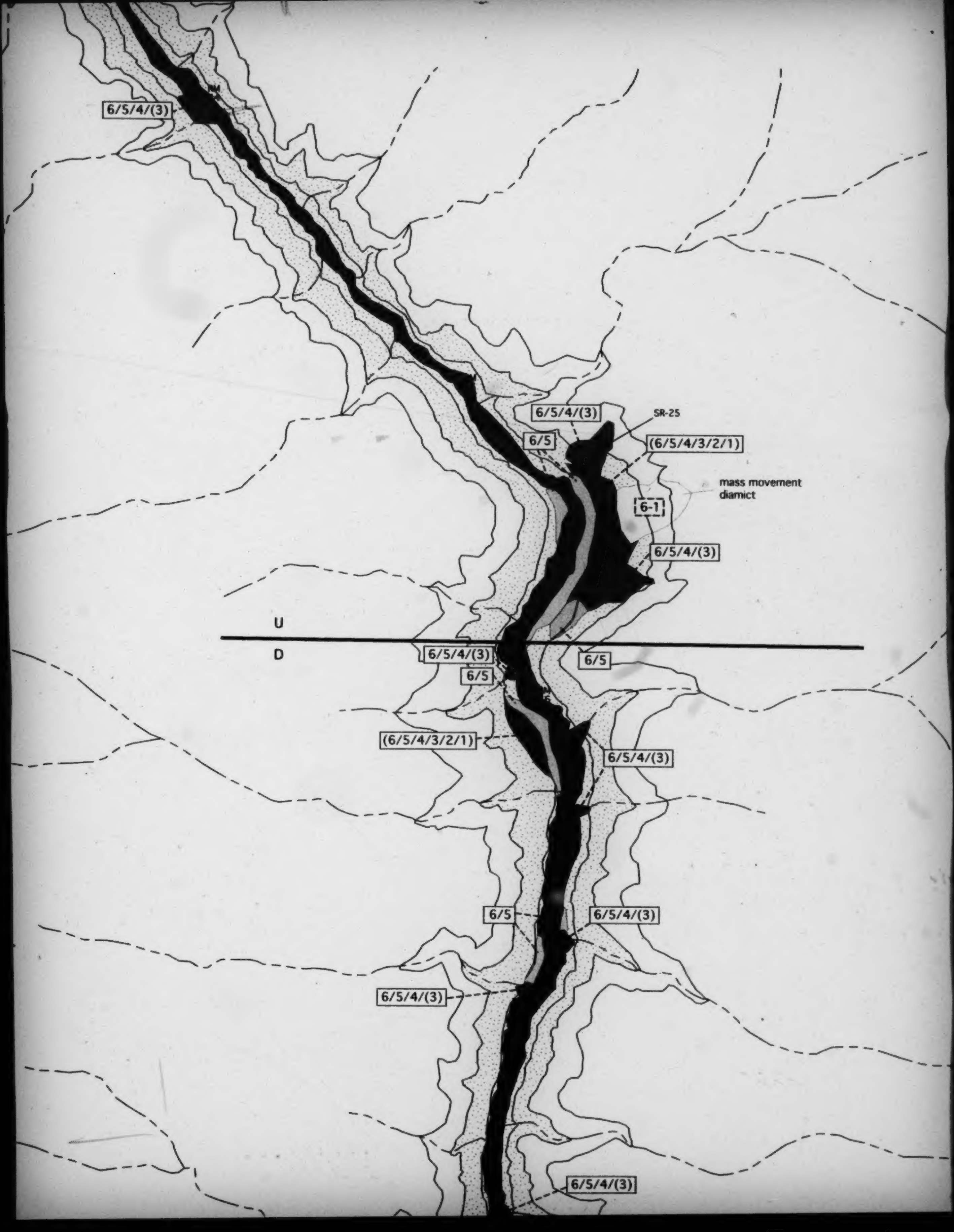
ene Alluvial Fan Sediments (Qaf1)

ene Alluvium (Qal1)

Cenozoic bedrock and undifferentiated surficial sediments
g Qcg1 & Qcg2)

fault lines: U = upthrown block; D = downthrown block

contour lines (elevation in feet above sea level)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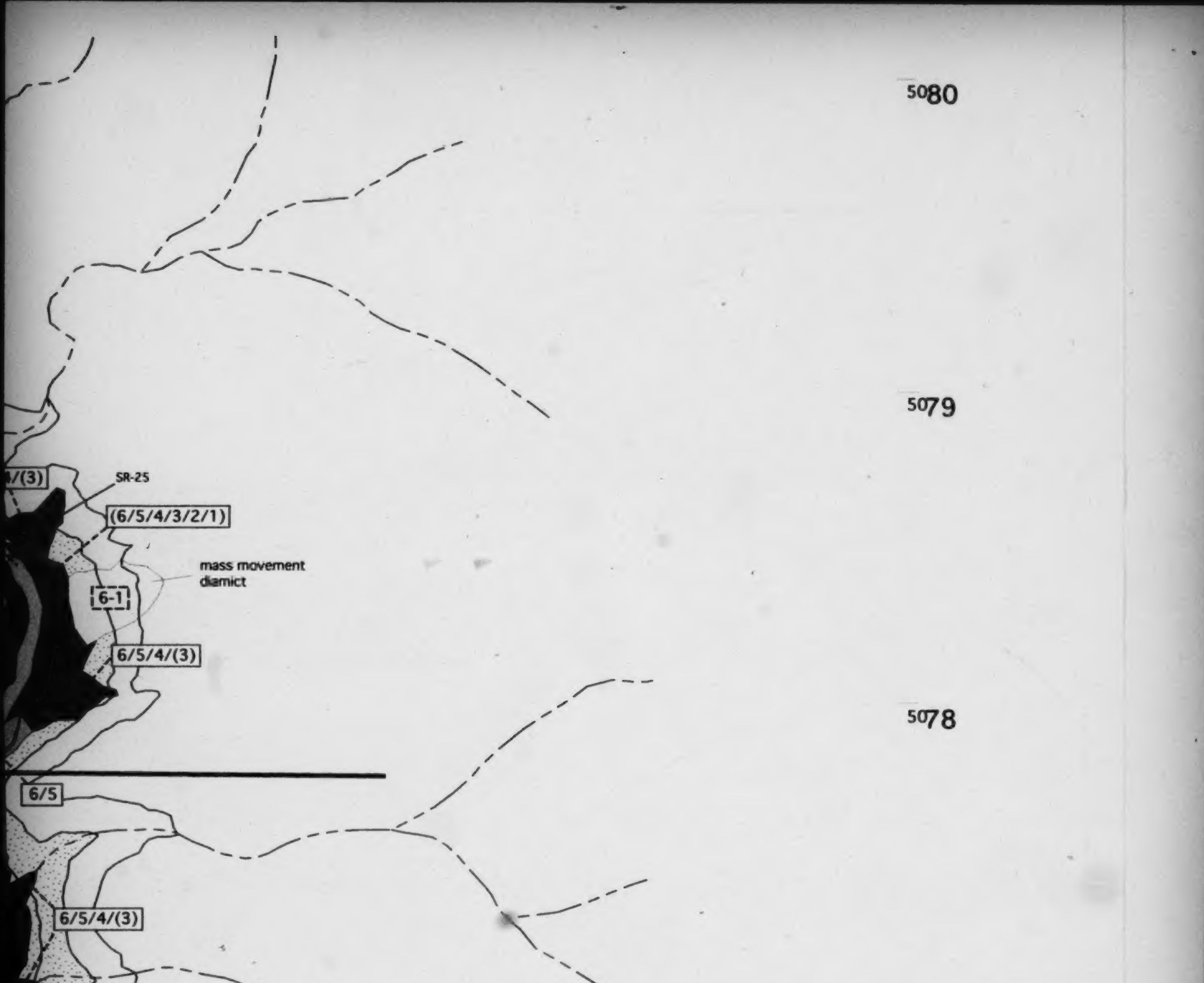
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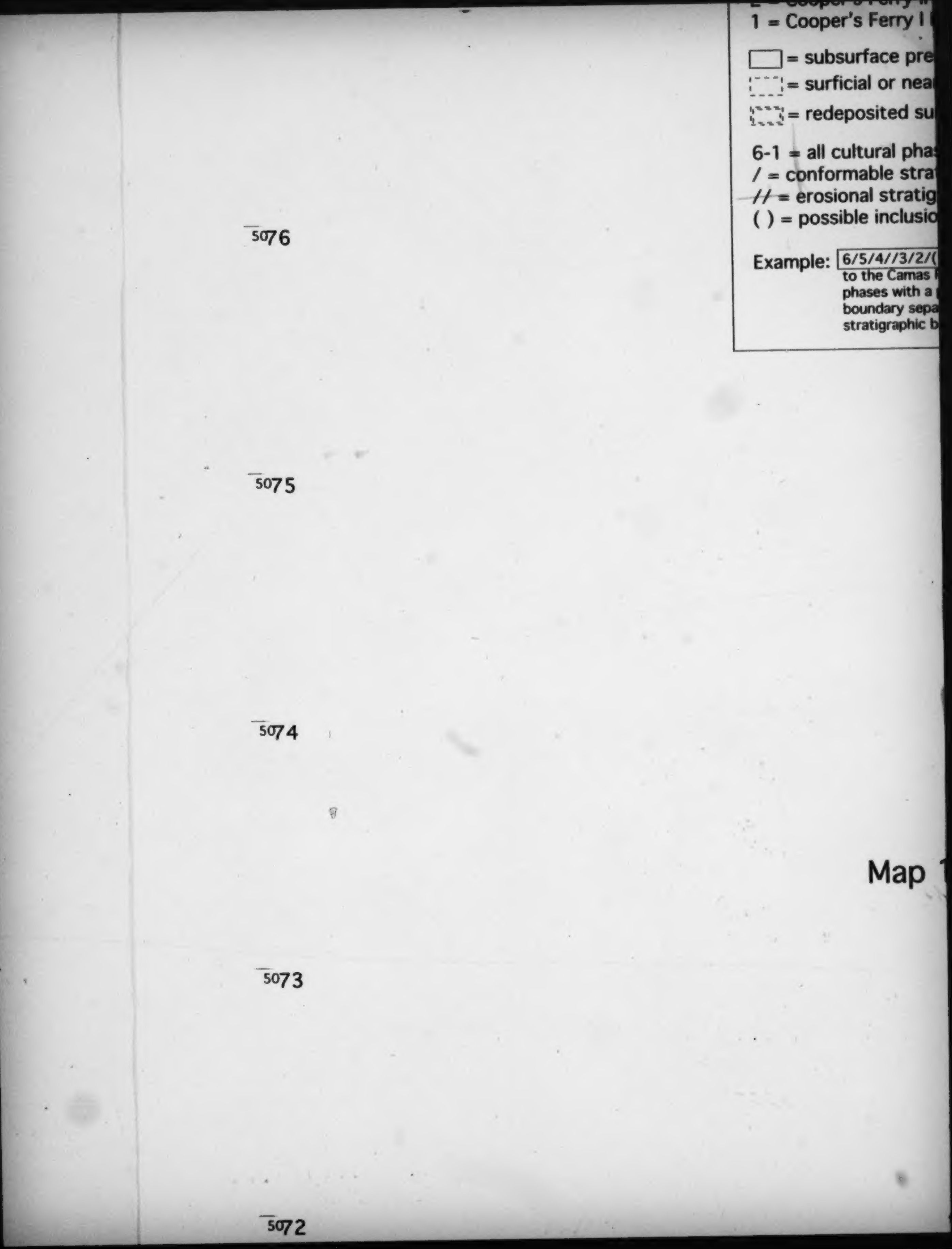
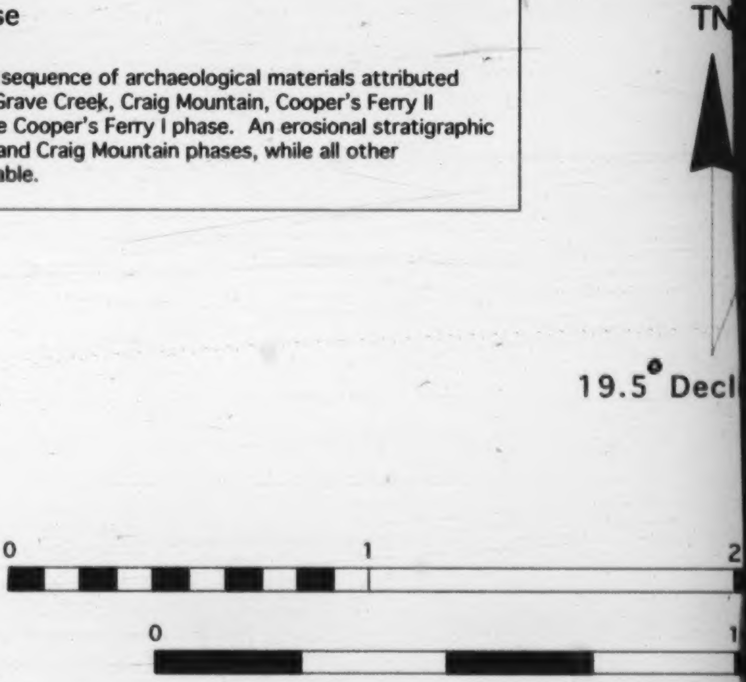

1 = Cooper's Ferry I
☐ = subsurface pre
⬚ = surficial or nea
⬚ = redeposited su
6-1 = all cultural pha
/ = conformable stra
// = erosional stratig
( ) = possible inclusio
Example: 6/5/4//3/2/(
to the Camas
phases with a
boundary sepa
stratigraphic b
^{50}76
^{50}75
^{50}74
^{50}73
^{50}72

Map

☐ = subsurface presence of cultural phase(s)
⬚ = surficial or near-surface presence of cultural phase(s)
⬚ = redeposited surficial or near-surface presence of cultural phase(s)

6-1 = all cultural phases
/ = conformable stratigraphic boundary
// = erosional stratigraphic boundary
( ) = possible inclusion of cultural phase

Example: 6/5/4//3/2/(1) = denotes a buried sequence of archaeological materials attributed to the Camas Prairie, Rocky Canyon, Grave Creek, Craig Mountain, Cooper's Ferry II phases with a possible inclusion of the Cooper's Ferry I phase. An erosional stratigraphic boundary separates the Grave Creek and Craig Mountain phases, while all other stratigraphic boundaries are conformable.



Map 1. Late Quaternary Surficial Geology Units and
in the Lower Salmon River Canyon, Idaho

ural phase(s)

materials attributed
, Cooper's Ferry II
n erosional stratigraphic
while all other

TN
MN
19.5° Declination

▇ Devils Garden Slide Diamict (Qls1)

▇ Middle Pleistocene Alluvial Fan Sedimen

▇ Middle Pleistocene Alluvium (Qal1)

☐ Mesozoic and Cenozoic bedrock and un
(including Qcg1 & Qcg2)

U D Dip-slip block fault lines: U = upthrown

1400 Topographic contour lines (elevation i

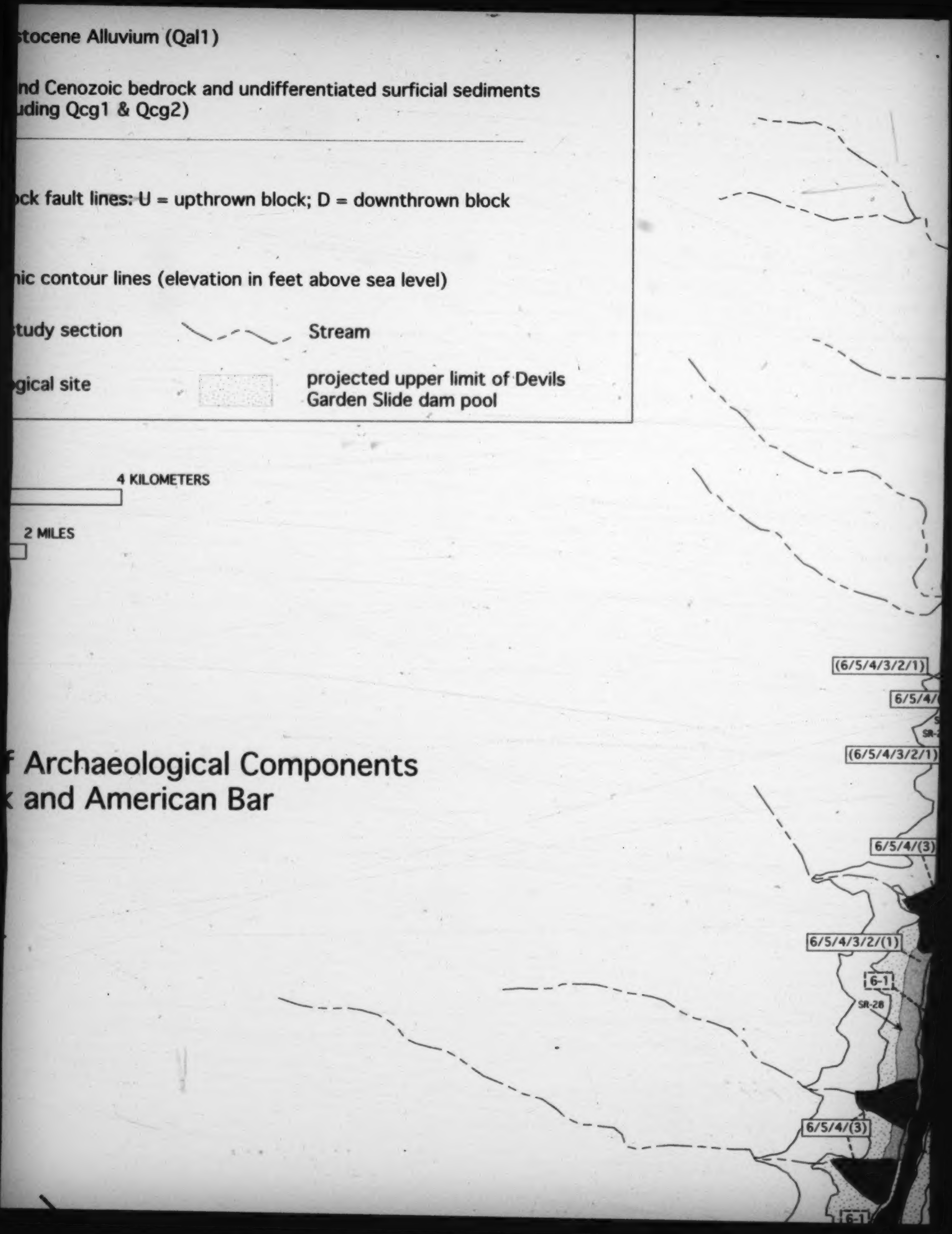
SR-28 Geologic study section

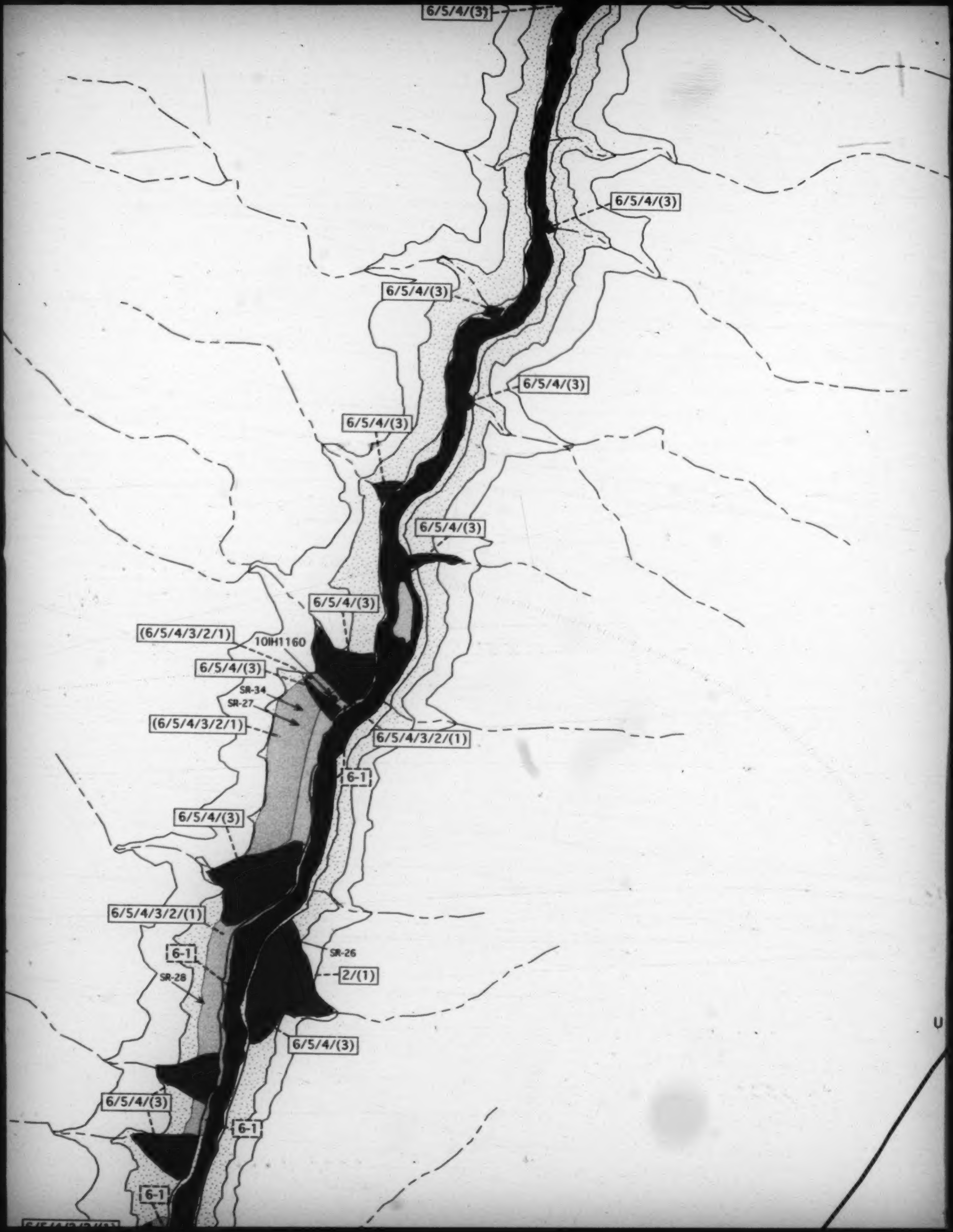
10IH73 ● Archaeological site

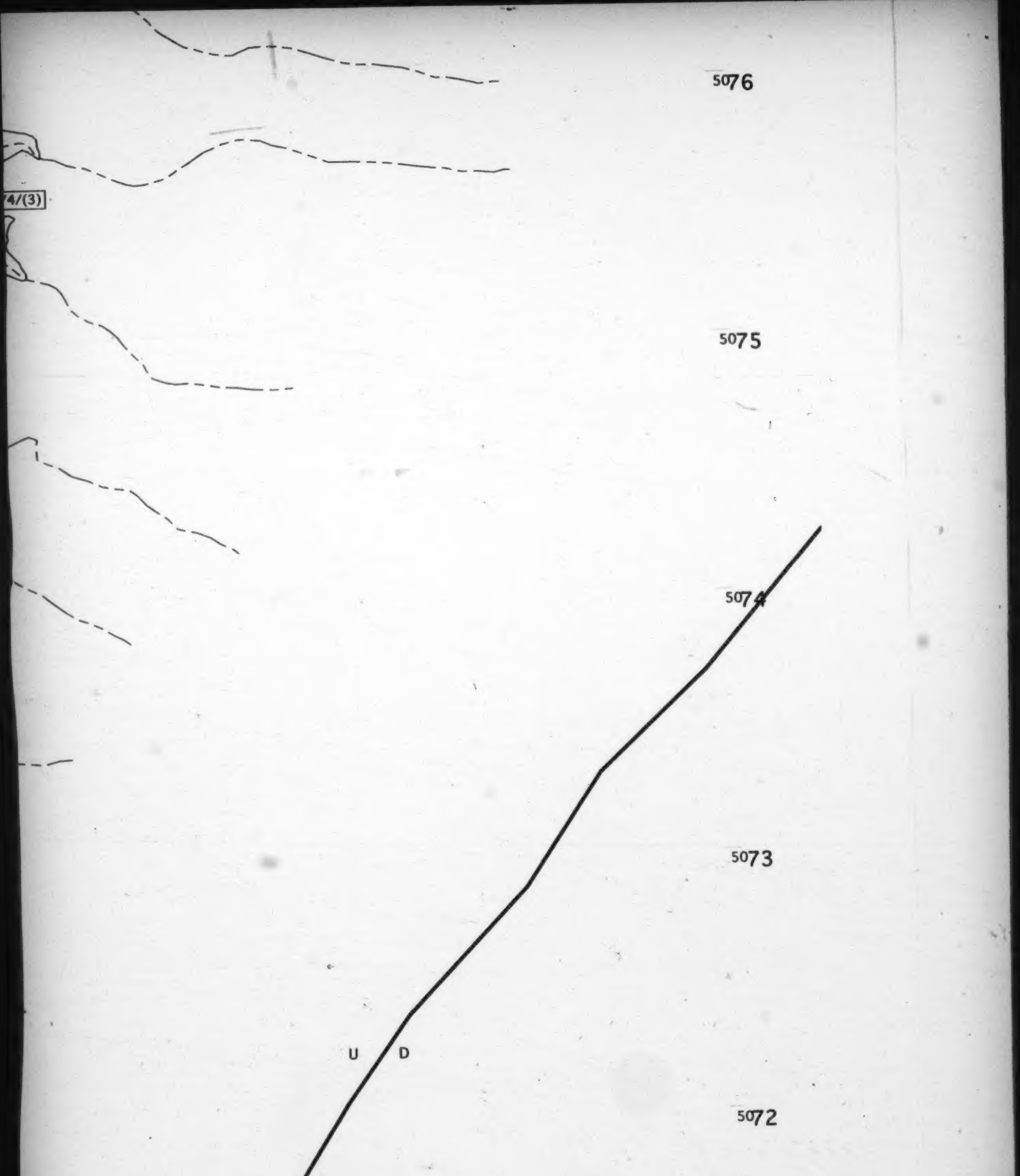
1
2
3
4 KILOMETERS
1
2 MILES

rficial Geology Units and Predicted Association of Archaeological
non River Canyon, Idaho, Between Hammer Creek and American B

f Archaeological Components
k and American Bar


stocene Alluvium (Qal1)
nd Cenozoic bedrock and undifferentiated surficial sediments
uding Qcg1 & Qcg2)
ock fault lines: U = upthrown block; D = downthrown block
nic contour lines (elevation in feet above sea level)
study section
Stream
gical site
projected upper limit of Devils Garden Slide dam pool
4 KILOMETERS
2 MILES
(6/5/4/3/2/1)
6/5/4/(
S
SR-2
(6/5/4/3/2/1)
6/5/4/(3)
6/5/4/3/2/(1)
6-1
SR-28
6/5/4/(3)
6-1


6/5/4/(3)
6/5/4/(3)
6/5/4/(3)
6/5/4/(3)
6/5/4/(3)
6/5/4/(3)
6/5/4/(3)
(6/5/4/3/2/1)
10IH1160
6/5/4/(3)
SR-34
SR-27
(6/5/4/3/2/1)
6/5/4/3/2/(1)
6-1
6/5/4/(3)
6/5/4/3/2/(1)
SR-26
6-1
SR-28
2/(1)
6/5/4/(3)
U
6/5/4/(3)
6-1
6-1


5076
74/(3)
5075
5074
5073
U
D
5072

5072

5071

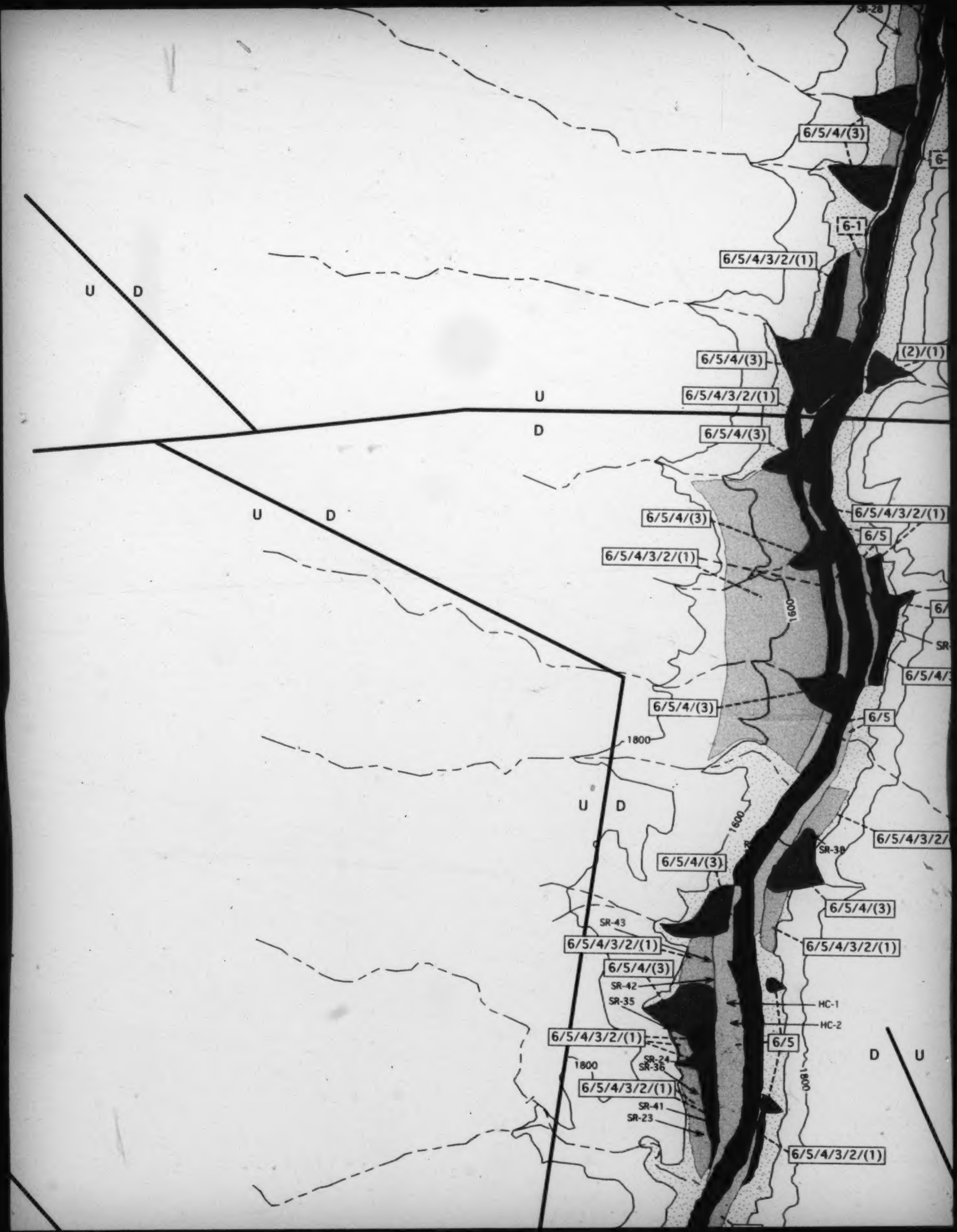
5070

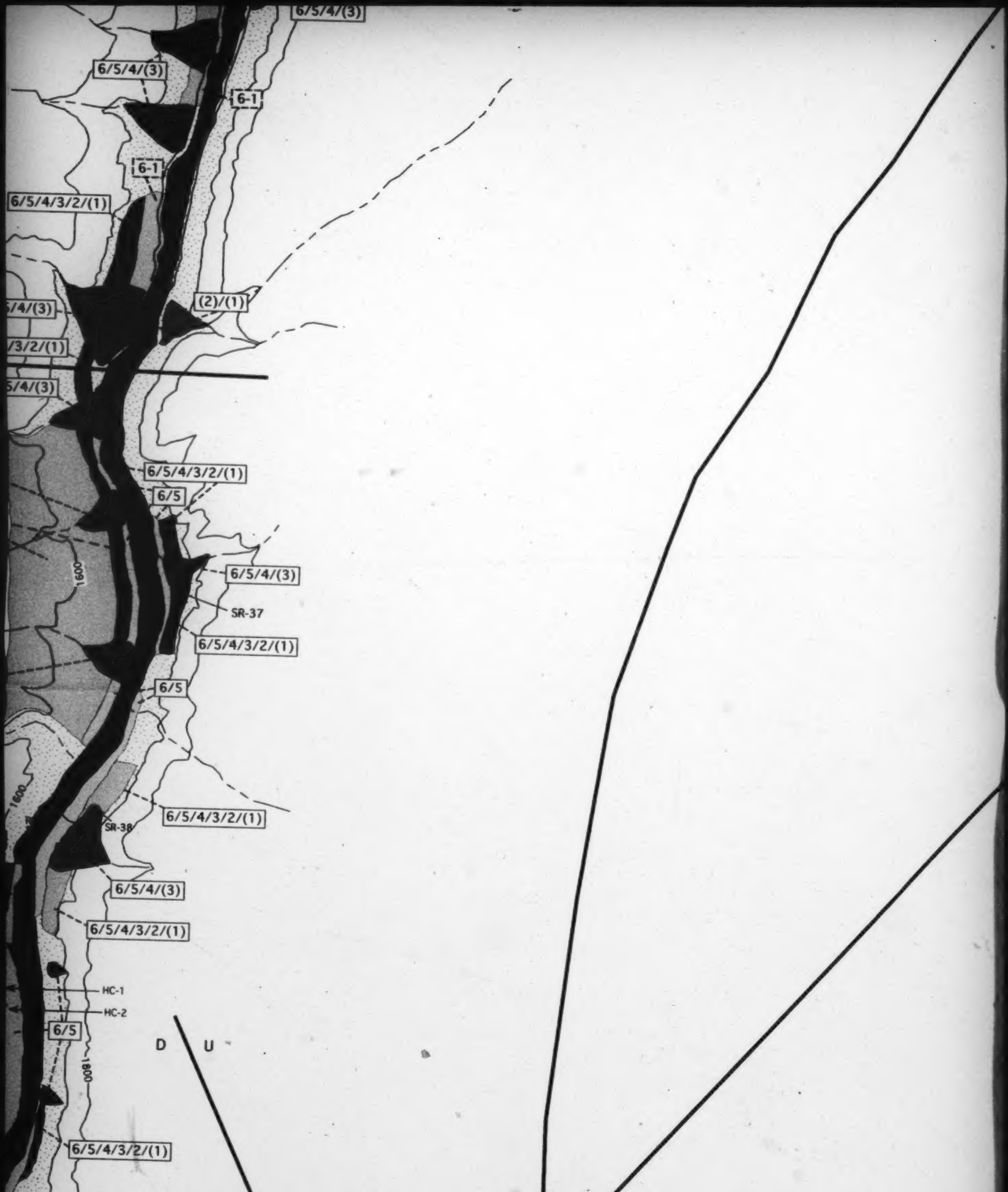
5069

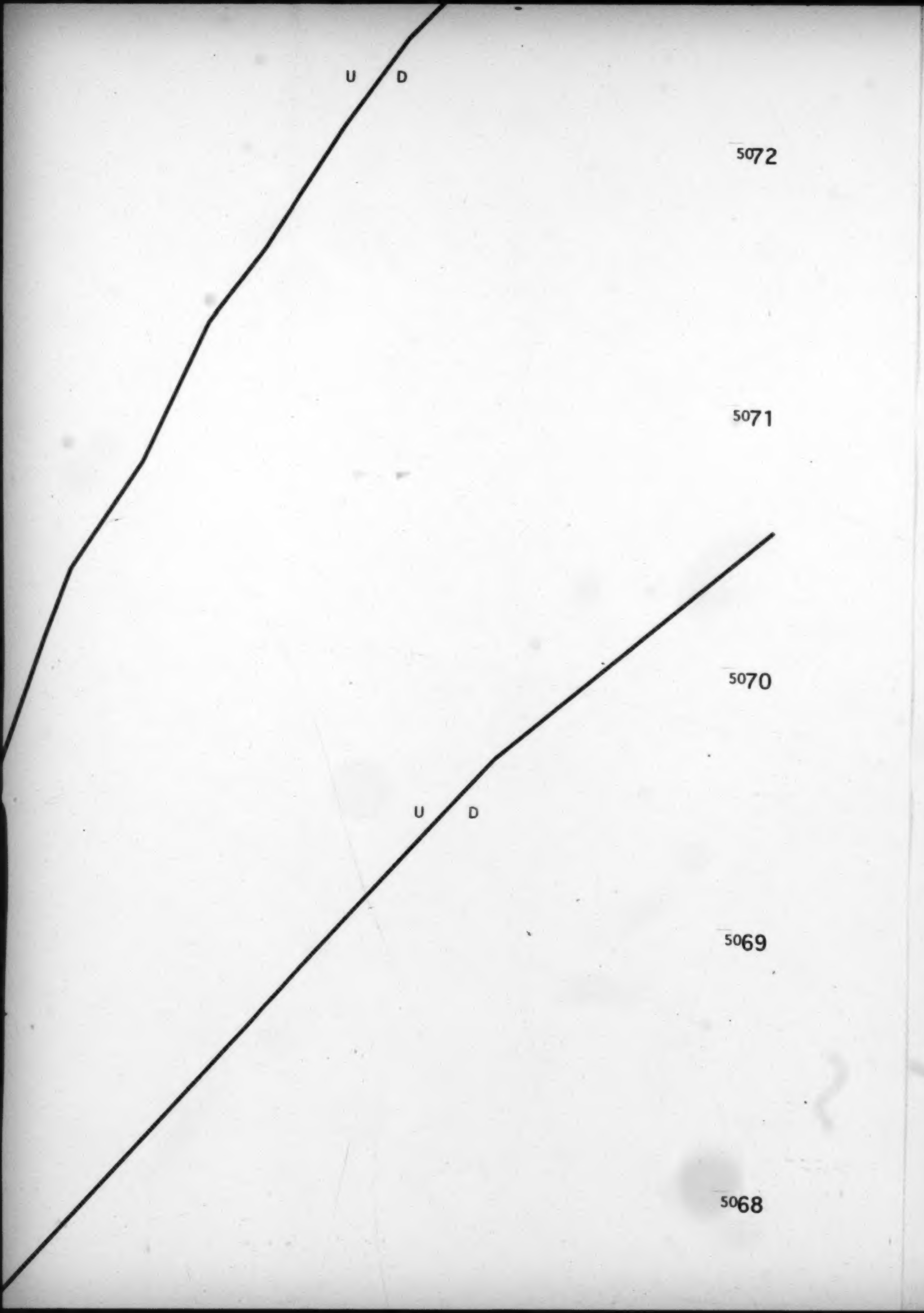
5068

U D

U D


SR-28
6/5/4/(3)
6-
6-1
6/5/4/3/2/(1)
U
D
6/5/4/(3)
(2)/(1)
6/5/4/3/2/(1)
U
D
6/5/4/(3)
U
D
6/5/4/(3)
6/5/4/3/2/(1)
6/5
6/5/4/3/2/(1)
1600
6/
SR-
6/5/4/3
6/5/4/(3)
6/5
1800
U
D
1600
6/5/4/3/2/
SR-38
6/5/4/(3)
6/5/4/(3)
SR-43
6/5/4/3/2/(1)
6/5/4/3/2/(1)
6/5/4/(3)
SR-42
SR-35
HC-1
HC-2
6/5/4/3/2/(1)
6/5
D
U
SR-24
SR-36
1800
1800
6/5/4/3/2/(1)
SR-41
SR-23
6/5/4/3/2/(1)


6/5/4/(3)
6/5/4/(3)
6-1
6-1
6/5/4/3/2/(1)
5/4/(3)
(2)/(1)
/3/2/(1)
5/4/(3)
6/5/4/3/2/(1)
6/5
1600
6/5/4/(3)
SR-37
6/5/4/3/2/(1)
6/5
1600
6/5/4/3/2/(1)
SR-38
6/5/4/(3)
6/5/4/3/2/(1)
HC-1
HC-2
6/5
D
U
1800
6/5/4/3/2/(1)
6/5


U
D
5072
5071
5070
U
D
5069
5068

$^{50}70$

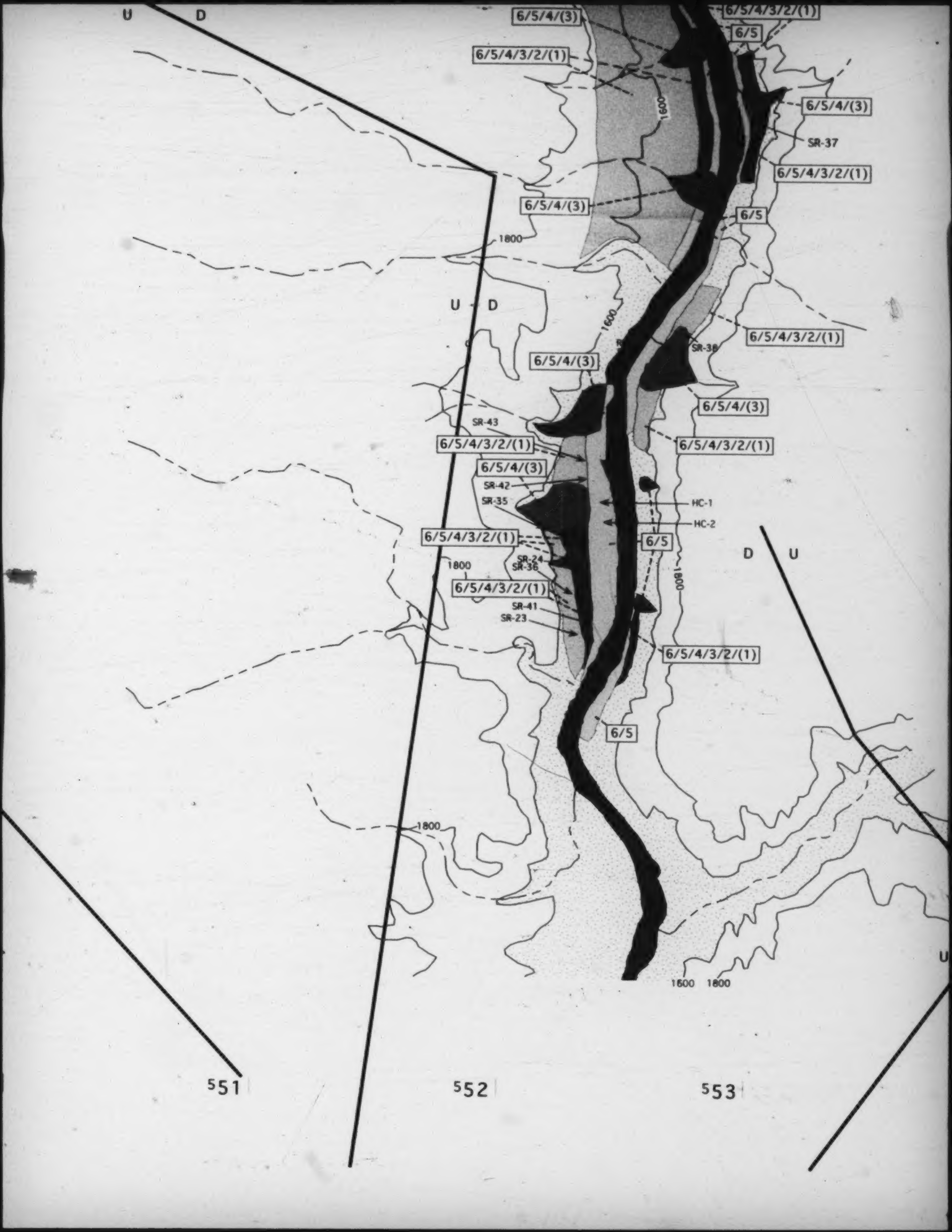
$^{50}69$

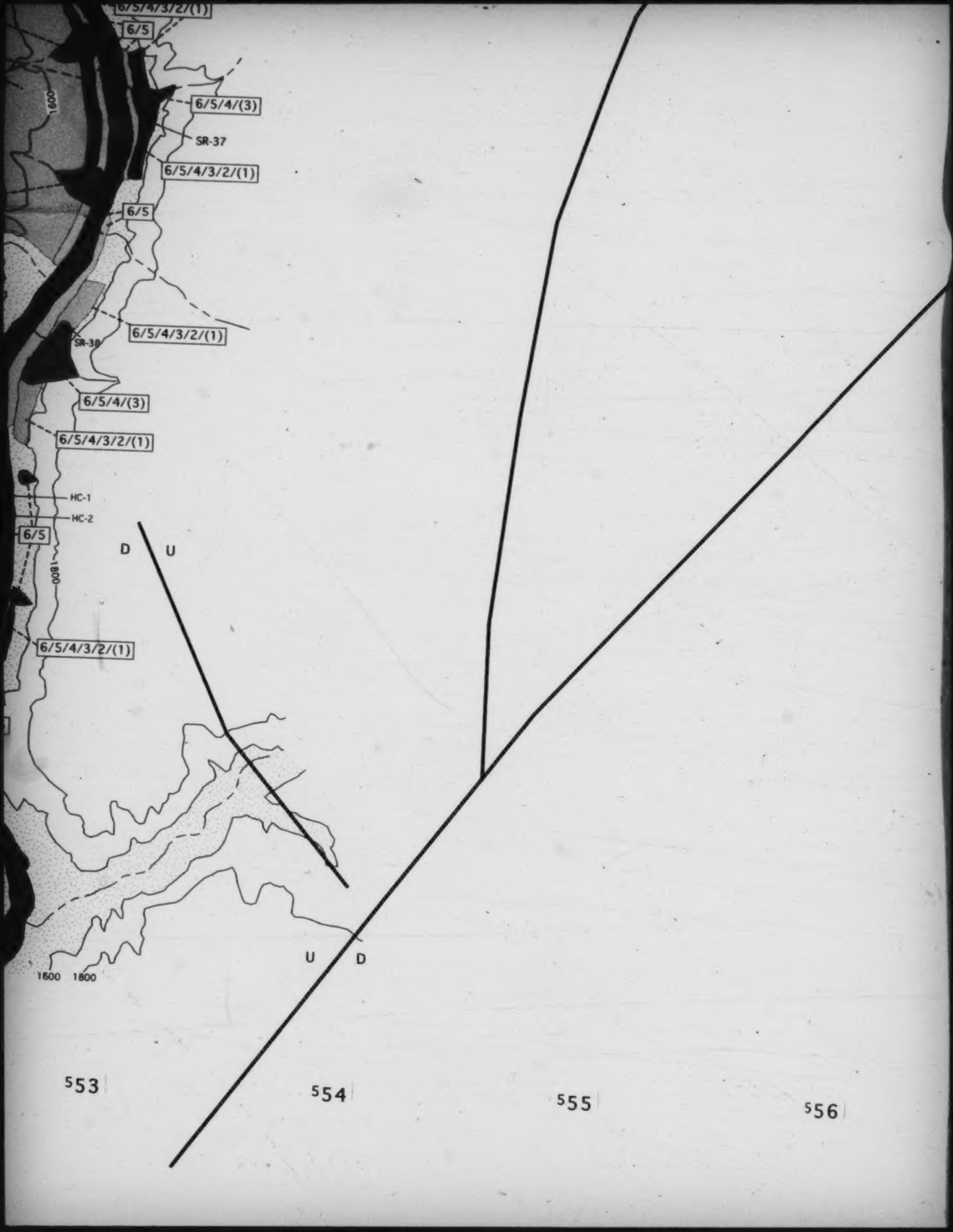
$^{50}68$

$^{50}67$

$^{5}43$ $^{5}44$ $^{5}45$

U
D
U
D
548
549
550
551


U
D
6/5/4/(3)
6/5/4/3/2/(1)
6/5
6/5/4/3/2/(1)
1600
6/5/4/(3)
SR-37
6/5/4/3/2/(1)
6/5/4/(3)
6/5
1800
U
D
1600
6/5/4/3/2/(1)
SR-38
6/5/4/(3)
6/5/4/(3)
SR-43
6/5/4/3/2/(1)
6/5/4/3/2/(1)
6/5/4/(3)
SR-42
SR-35
HC-1
HC-2
6/5/4/3/2/(1)
6/5
D
U
SR-24
SR-36
1800
1800
6/5/4/3/2/(1)
SR-41
SR-23
6/5/4/3/2/(1)
6/5
1800
1600
1800
U
551
552
553


6/5/4/3/2/(1)
6/5
1600
6/5/4/(3)
SR-37
6/5/4/3/2/(1)
6/5
6/5/4/3/2/(1)
SR-30
6/5/4/(3)
6/5/4/3/2/(1)
HC-1
HC-2
6/5
D
U
1800
6/5/4/3/2/(1)
U
D
1600
1800
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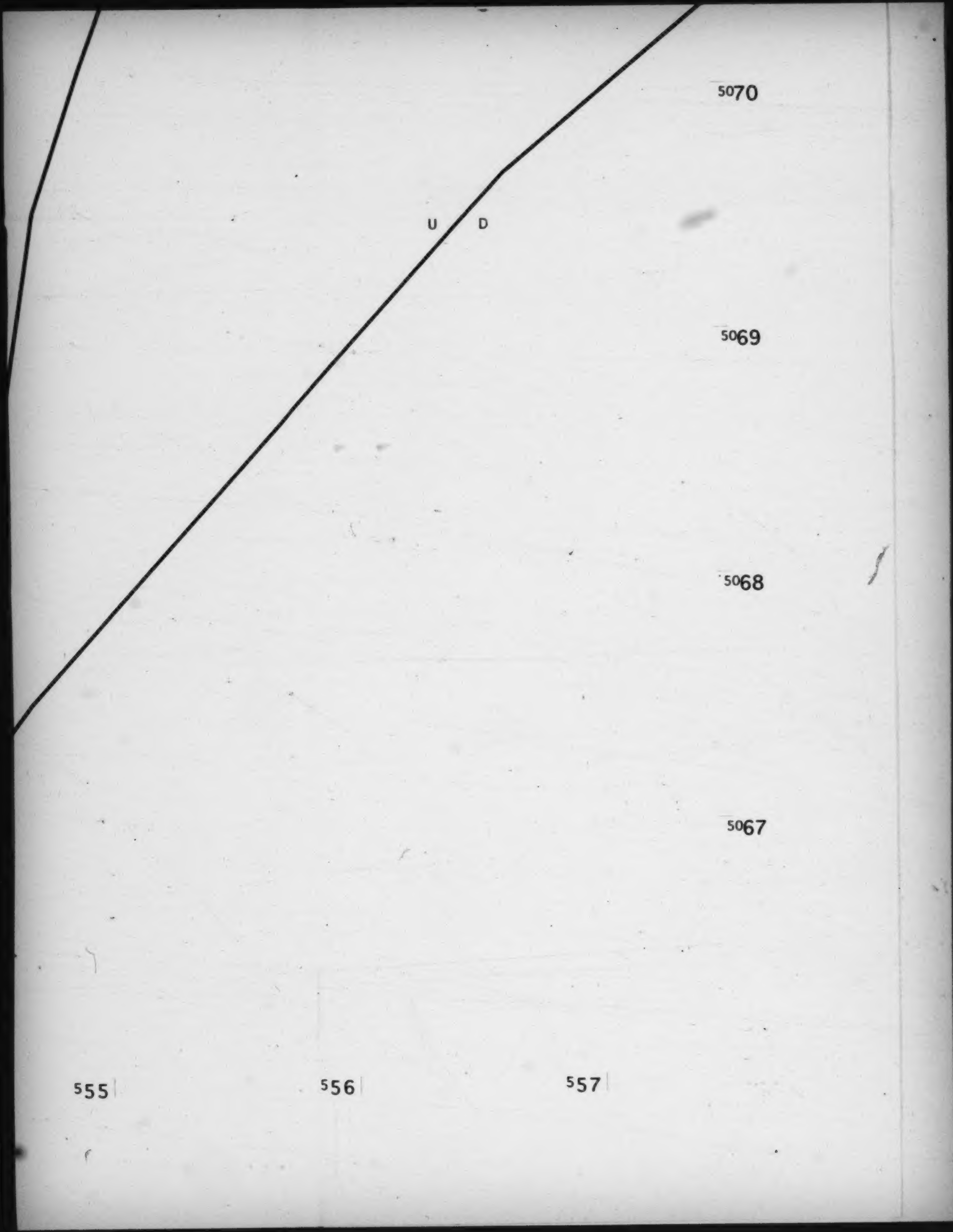
556


5070
U
D
5069
5068
5067
555
556
557